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THE JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY

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LONDON

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SPERRY ELECTRIC
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Secretary's News Letter

MAY 1952

ON 28th March Mr. D. C. Smith and I visited the English Electric Company, at Preston, the home of the Canberra. During the day we saw over the works and in the evening we went to a meeting of the Preston Branch, when the motion, "This House considers that 'Prototype Design Suffers from Consideration of Future Production,'" was debated.

There was a monetary prize of two guineas for the best speech of the evening: this was won by Mr. Hollick.

Many speakers took part in the debate and, since the subject gave rise to one or two sore points, there was much passionate eloquence. Mr. J. C. King, the Branch Secretary, acted as Chairman and firmly kept the meeting under control.

At Cranfield the Common Room Dinner was held on Friday 4th April. I saw many well-kent faces, and very much enjoyed a function at which I had no responsibilities. In his reply to the toast of the College, the Principal, Sir Victor Goddard, deplored the barrenness of the walls of College rooms, and asked the Royal Aeronautical Society for pictures and photographs of aviation interest. Here is a chance for members to help the College to decorate its Halls.

The following day, Saturday 5th April, I went on to Birmingham, where the Birmingham Branch was holding its Annual Dinner. Once again I met Mr. N. E. Rowe, the tireless Chairman of the Branches Committee. (He turns up again in this News Letter—at Luton.) I know he is called "Nero." I think the initial consonant should be changed, and Mr. Rowe re-bynamed "Hero."

Luckily I walked to the Dinner, so I was able to outmanoeuvre the Birmingham traffic system, and reach my destination without difficulty. The Dinner was supplemented by an entertainment by a variety troupe. This was given a very good reception. Mr. G. E. Firkin, the Branch President, and Mr. C. P. Homes, the Branch Secretary, are to be congratulated on the success of the evening.

One of the last of the Main Society Lectures was held at Luton on 24th April at Luton High School for Girls, when Mr. J. E. Walker, A.F.R.Ae.S., de Havilland Aircraft Co., gave his lecture on "Fuel Systems for Turbine Driven Aircraft." Mr. G. H. Dowty, Vice-President, was introduced by the Branch Chairman and he took the Chair. The lecture was interesting and instructive, and brought forth some very pertinent questions. There was a very good attendance, no fewer than seven Branches being represented.

After the lecture the Branch entertained a large number of guests at the Royal Hotel. The Branch President, Air Vice-Marshal Sir Conrad Collier, proposed the health of the Society, and Mr. Dowty replied. Among the guests was the Mayor of Luton, who replied to the toast of the guests, wittily given by the Branch Chairman, Mr. F. S. Lester. It would appear from the Mayor's remarks that Luton is a town of extremes—a town of hats and nylons.

Among those present was Mr. N. E. Rowe.

Most members will already know of the loss the Society has had in the death of the Honorary Librarian, Mr. J. E. Hodgson. Elsewhere there is an appreciation of him and the work he did for the Society: I never had the pleasure of meeting him, but we corresponded, he being very friendly and helpful on all occasions.

A. M. Ballantyne

Secretary

NOTICES

ELECTION OF PRESIDENT FOR 1952-1953

Mr. G. H. Dowty, *Fellow* and Vice-President, was elected President by the Council at their April Meeting. Mr. Dowty takes office at the Annual General Meeting on 7th May 1952.

WHITSUN HOLIDAYS

The Offices and Library of the Society will be closed from 5 p.m. on Friday 30th May to 9 a.m. on Tuesday 3rd June 1952 for the Whitsun Holidays.

CLOSING OF THE LIBRARY

The Library will be closed on Monday, Tuesday and Wednesday, 26th, 27th and 28th May 1952 for the Associate Fellowship Examinations, which will be held there.

GARDEN PARTY 15th JUNE 1952

Members are reminded that the Society's Annual Garden Party will be held on Sunday 15th June 1952 at White Waltham Aerodrome, near Maidenhead, by kind permission of the Ministry of Civil Aviation and the Fairey Aviation Co. Ltd.

An application form for tickets has been sent to all home members. Already quite a number of applications for tickets have been received and members are advised to apply as soon as possible as the numbers may have to be limited.

Personal aircraft and training aircraft from this country and abroad will take part in the Flying Programme. In addition there will be a gliding display and a number of helicopters will be in the programme.

CONTENTS OF THE MAY JOURNAL

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Fifth Louis Bleriot Lecture—The Future of the Flying Boat, H. Knowler, A.M.I.C.E., F.R.Ae.S.

Control Surface Flutter, E. G. Broadbent, M.A., A.F.R.Ae.S., and W. T. Kirkby, A.M.I.Mech.E., A.F.R.Ae.S.

Graphical Analysis of Trans-Canada Airlines' Progress on the North American Routes 1946-1950, Adam Jaworski.

New Zealand Division—Third Annual Report.

Reviews. Additions to the Library.

(An annual sum of £250 is available for premium awards for papers published in the Journal. These premium awards are usually 15 guineas each. Members and non-members of the Society are invited to submit papers on any aspect of aeronautics.)

THE AERONAUTICAL QUARTERLY—VOLUME III, PART IV

The Aeronautical Quarterly, Volume III, Part IV, February, is available from the offices of the Society, at 7s. 6d. a copy to members (7s. 9d. post paid) and 10s. (10s. 3d. post paid) to non-members.

The contents of Part IV are:—

The Automatic Control of an Aeroplane in the Landing Approach onto an Aircraft Carrier	J. B. Helliwell
Supersonic Flow over Thin Symmetrical Wings with given Surface Pressure Distribution	F. A. Goldsworthy
Longitudinal Waves in Beams	R. E. D. Bishop
A Note on Supersonic Wing Integral Equations in Unsteady Flow	John W. Miles
The Theory of Aerofoils in Unsteady Motion	J. R. M. Radok
Index to Volume IV.	

Copies of Volume III, Parts I, II and III, are still available from the offices of the Society at 7s. 9d. a copy to members of the Society, post paid, or 10s. 3d. to non-members, post paid.

GRADUATES' AND STUDENTS' SECTION

The attention of Graduates and Students is drawn to the following visits arranged for the Section:

Saturday 5th July. All day visit to Bristol Aeroplane Company's works at Filton, to see the latest commercial aircraft produced by the Company. Lunch will be served at the works. The party will travel by coach from London, leaving at approximately 9 a.m. (returning 10.30 p.m.) for which the estimated fare is 25/-.

Wednesday 13th August. An afternoon visit to the de Havilland Engine Co., Leavesden, to see gas turbine production.

Saturday 25th October. All day visit to the College of Aeronautics, Cranfield, to see laboratories, etc. Lunch will be served.

Graduates and Students are asked to notify the Honorary Visits Secretary (M. K. Bowden, 3 Limes Road, Weybridge, Surrey) immediately if they are interested in the visits so that transport and other arrangements may be made.

THE BUSK STUDENTSHIP IN AERONAUTICS

The Trusteeship of the Edward Busk Studentship in Aeronautics has now been transferred to Aeronautical Trusts Ltd., and in future the Studentship will be administered by the Society.

This Studentship was established in memory of Edward Teshmaker Busk, who lost his life in 1914 while flying an experimental aeroplane. In 1915 the Gold Medal of the Society was awarded to him posthumously, for his work in aeronautics.

The Studentship is of the value of about £165, tenable for one year from 18th October, and is open to any man or woman who is a British Subject and of British descent who has not attained the age of 25 years on 18th October 1952.

Application forms, giving full conditions of the studentship, which must be returned by 1st June 1952, can be obtained from the Secretary of the Society.

MEMBERS' NEW APPOINTMENTS

P. A. R. BREMBRIDGE (*Associate*) has been appointed a director of The British Independent Air Transport Association. He was formerly an aviation specialist with the research department of the Conservative Party.

R. S. DICKSON (*Associate Fellow*) is taking up a design position with the Lockheed Aircraft Corporation, Burbank, California.

C. F. JOY (*Associate Fellow*), Assistant Chief Designer of Handley Page Ltd. since 1947, has been appointed Deputy Chief Designer.

D. M. LAMBERT (*Associate*) has been promoted to Aero Sales Manager (Technical) of Armstrong Siddeley Motors Ltd., Coventry.

G. H. LEE (*Fellow*), Chief Aerodynamicist, Handley Page Ltd., has been appointed Assistant Chief Designer—Aerodynamics.

Captain (E.) M. LUBY, R.N. (Ret'd) (*Fellow*) at present Director of Engine Research and Development (Air) at the Ministry of Supply, is taking up the position of Director and General Manager of Rotax Ltd., in July. In addition, he will be appointed a member of the Board of Joseph Lucas (Gas Turbine Equipment) Ltd.

W. T. NEILL (*Associate*), formerly Assistant Production Manager, has been appointed Production Manager of de Havilland Propellers Ltd., Lostock.

K. C. PRATT (*Associate Fellow*), formerly in charge of the Test Department, Handley Page Ltd., has been appointed Development and Test Engineer.

R. H. SANDIFER (*Fellow*), formerly Chief Stressman, Handley Page Ltd., has been appointed Assistant Chief Designer—Structures.

F. TYSON (*Associate Fellow*), Assistant Chief Stressman, Handley Page Ltd. since 1947, has been appointed Chief Stressman.

C. O. VERNON (*Associate Fellow*), formerly Deputy Chief of the Aerodynamics Department, Handley Page Ltd., has been appointed Chief Aerodynamicist.

SIR ROBERT WATSON-WATT (*Fellow*) has been appointed Adviser to the Defence Research Board in the field of radar and electronics by the Canadian Defence Department.

HONOURS AWARDED

Sir ROY FEDDEN (*Fellow*), who is a Founder Member of the Society of Aeronautical Weight Engineers Inc., has been elected an Honorary Fellow of that body.

JOHN J. IDE has been awarded a special Gold Medal by the National Advisory Committee for Aeronautics in recognition of his having served " faithfully and with distinction " as N.A.C.A.'s representative in Europe from 1921-1950.

JOURNAL PREMIUM AWARDS

The following Premium Awards, each for fifteen guineas, have been awarded for papers published in the JOURNAL in 1951:—

R. H. Whitby, D.I.C., A.R.C.S., B.Sc., A.F.R.Ae.S. (Assistant to the Controller Research and Special Development, British European Airways) for his paper on " Some Operational Problems of Public Transport Helicopters." (January 1951 JOURNAL.)

Group Captain J. A. Newton, A.F.C., A.R.Ae.S. (Chief of the Accident Investigation Unit, I.C.A.O., Montreal) for his paper on " The Human Factor in Aircraft Accidents." (February 1951 JOURNAL.)

D. Williams, D.Sc., M.I.Mech.E., A.F.R.Ae.S. (Structures Department, Royal Aircraft Establishment) for his paper on " Note on the Distortion Characteristics of Swept and Cranked Wings in Relation to Flutter and other Aeroelastic Phenomena." (February 1951 JOURNAL.)

F. H. Parker (Development Engineer, The Bristol Aeroplane Co. Ltd.) for his paper on " Metal Adhesive Processes." (March 1951 JOURNAL.)

Bengt Jakobsson, Dr.Sc.(Eng.), A.F.R.Ae.S. (Performance Engineer, Svenska Flygmotor, Aktiebolaget) for his paper on " Definition and Measurement of Jet Engine Thrust." (April 1951 JOURNAL.)

Professor A. D. Young, M.A., F.R.Ae.S. (Professor of Aerodynamics, College of Aeronautics) for his paper on " Boundary Layer and Skin Friction in High-Speed Flow." (May 1951 JOURNAL).

Olaf Thornton, A.F.R.Ae.S. (A/D Technical Development, Plans, Ministry of Supply) for his paper on " Planning and Aircraft Development." (May 1951 JOURNAL.)

D. J. Lambert, A.F.R.Ae.S. (Aerodynamics Department, Vickers-Armstrongs Ltd., Weybridge) for his paper on " The Derivation and Estimation of Aerodynamic Loads for Stressing Purposes." (September 1951 JOURNAL.)

Squadron Leader J. D. Derry (Experimental Test Pilot, de Havilland Aircraft Co. Ltd.) for his paper on " High Speed Flying." (October 1951 JOURNAL.)

Professor A. D. Baxter, M.Eng., F.R.Ae.S. (Head of the Department of Aircraft Propulsion, College of Aeronautics) for his paper on " Power Plants for High-Speed Aircraft." (October 1951 JOURNAL.)

A. W. Hotson, B.Sc., A.M.I.Mech.E. (Strength and Design Division, Structures Department, Royal Aircraft Establishment) for his paper on " Recent Development in Methods of Strength Testing Pressurised Fuselages." (November 1951 JOURNAL.)

W. F. Hilton, Ph.D. (Chief Aerodynamicist, Sir W. G. Armstrong-Whitworth Aircraft Co. Ltd.) for his paper on " Supersonic Propellers." (December 1951 JOURNAL.)

DIARY

LONDON.

May 29th.
40TH WILBUR WRIGHT MEMORIAL LECTURE—Prophecy and Achievement in Aeronautics. Sir Harry M. Garner. Institution of Civil Engineers, Great George St., London. 6 p.m.

June 15th.
Garden Party. White Waltham Aerodrome, near Maidenhead, Berks. 2.30-6.30 p.m. (*See special notice.*)

BRANCHES.

May 14th.
Chester—Annual General Meeting. Grosvenor Hotel. 7.30 p.m.
Weybridge—Annual General Meeting. Vickers-Armstrongs Ltd. 6 p.m.

May 19th.
Glasgow—Aircraft Stability and Control. A. W. Babister. Royal Technical College. 7 p.m.
Halton—Films. Branch Headquarters. 6.45 p.m.

May 23rd.
Birmingham—Annual General Meeting. White Horse Hotel. 7 p.m.

May 26th.
Halton—Lecturette by a Junior Member. Branch Headquarters. 6.45 p.m.

June 9th.
Halton—Flying Boats. H. Knowler. Branch Headquarters. 6.45 p.m.

June 16th.
Glasgow—A History of Aeronautics in Scotland. I. R. Liddel. Royal Technical College. 7 p.m.

June 23rd.
Halton—Films. Branch Headquarters. 6.45 p.m.

ELECTIONS

The following is a list of new members and transfers of membership of the Society:—

Associate Fellows

Allan Barker
Leonard Blakelock
Francis Henry Borlace (*from Graduate*)
Alan Charles Conolly (*from Graduate*)
Thomas Frederick Curragh (*from Graduate*)
Jacques Elsner
Andrew Wauchope Fraser (*from Associate*)
Rangaswamiengar Srinivasa Gopalachar
James Arnot Hamilton (*from Graduate*)
Peter William Harper (*from Graduate*)
Albert G. G. Herreng
Jack Hughes (*from Graduate*)
Philip Auriol Edgar Jeffery (*from Graduate*)
Alan Norman Knowles (*from Graduate*)
Alfred Charles Martin (*from Graduate*)
Alan John Leonard Mitchell (*from Graduate*)
Gerald Charles Stokes Montanaro
Catherine Gertrude Newton (*from Graduate*)
Norman Horace Payne
Derek Price
Albert William Prouse (*from Graduate*)
Alan Henry Robinson (*from Graduate*)
Frank Smith (*from Graduate*)
Henry Lambert Garbutt Sunley (*from Graduate*)
Philip Harold Townshend (*from Graduate*)
Reginald William Ward (*from Companion*)
George Macmillan Watson

Associates

Dennis Wyatt Allen
Matthew Cormie Ferguson
Henry William Goodinge
Lionel Herbert Greenman
Torsten Hugo Lindbom

John Drake Langdon (*from Student*)
Joseph Richard Saunders
Percy Cecil Vigar
Albert Henry Whitehouse

Graduates

Patrick Edward Stanbrook Batey (*from Student*)
Anthony Robert Beauchamp
Mieczyslaw Stanislaw Ciecek
John Edward Crane (*from Student*)
John Sidney Crick
David Fletcher
Richard Neville Hadcock
Peter James Harradine
Alan Langrish Knight (*from Student*)
Ivan Stewart McLeish
Graham Stanley Pool
Kenneth Roy Sherhod
Kenneth Frederick Wood
John William Herbert Woof (*from Student*)

Students

Ian Albert Moore Hall
John Douglas Jones
William Andrew Lemmer
James Michael O'Connell
Robert John Sellars
Jan Sladkus
John Targett

Correction to the April 1952 JOURNAL

Under the heading *Companion*—Clause Evelyn Bowden should read *Claude* Evelyn Bowden.

ACKNOWLEDGMENTS

The Council acknowledge with grateful thanks the return of back numbers of the JOURNAL from Wing Commander R. A. C. Brie, *Associate Fellow*; and G. C. D. Russell, Esq., *Associate Fellow*.

CORRECTION TO APRIL JOURNAL

The following misprints should be corrected in the paper, "A Method of Estimating the Loading on an Elastic Airframe," by B. A. Hunn, B.Sc., pp. 261-278, in the April 1951 JOURNAL:—

page 265 15 lines from foot of page, for $b_{\ n}$ read b_{vn}

page 268 In the first formula, for $f_{\ s}$ read f_{vs}

page 273 Centre of the page (line 11), for $\mu = \frac{C_L c}{2b}$ read $\gamma = \frac{C_L c}{2b}$

page 274 Line 8, for $f_{\ s}$ read f_{vs}
Line 10, for $F_{v} =^{s}$ read F_{vs}

JOURNAL BINDING

Members are reminded that a special leaflet on JOURNAL binding for the 1951 Volume and for 1952 was enclosed with the December JOURNAL. Copies of this leaflet are available on application to the Society.

CHANGES OF ADDRESS

To assist in keeping the records of members correct and up to date the Secretary will be glad if all members will notify him as soon as possible of changes of address.

When notifying changes please give the following particulars:—

Name (in block letters).
Grade of membership.
New address (in block letters).
Old address.

Changes of address must be received *before the 15th of the month* in order to be effective for the JOURNAL for the following month.

John Edmund Hodgson

Honorary Fellow

1875-1952

THE NAME OF J. E. HODGSON has been familiar to members of the Royal Aeronautical Society for over a quarter of a century, as the Honorary Librarian. He was appointed Honorary Librarian at a Council Meeting held on 23rd October 1923, at which the author of the memoir was present, then, as a Member of Council. In the fruitful years he served the Society so well and so disinterestedly, the advice and practical help he so readily gave, have made the Library of the Society one of the most renowned in the world.

Although in the last twelve months he had been failing in health and had been prevented from attending those functions of the Society which in the past he had so seldom missed, he did not overlook anything which might add to the glory of the Society's library. Only six weeks before his death on 10th April 1952 (the day before his 77th birthday) he informed the Secretary that a copy, published in 1684, of that rare work Bishop Wilkins' *A Discovery of a New World* (with a chapter on Flying to the Moon) would be coming up for sale and advising it should be bought. It is now in the Society's library.

On 12th January 1926 the Society celebrated the 60th Anniversary of its foundation, by a Conversazione in the Science Museum, South Kensington. During that evening Hodgson, in an address to members of the Society and many distinguished guests, finished on a note which showed his clarity of vision in air matters. "If by the exercise of their influence, as individual members not less than as an organised body, they helped to make it more clearly realised that this country, while remaining faithful to its great tradition as a seafaring race, must develop an 'air sense' and become an air-faring people, then the Society would have added to its many great services to the Science of Aeronautics, no less great a service to the nation and to the Empire."

Only two years previously the Oxford University Press had published his monumental *History of Aeronautics in Great Britain*, a work which became a classic in his own life time. Its scholarship and research showed the quality of the man. Hodgson was learned in literature, a lover of fine books, fine printing and fine bindings, and he spoke and wrote with authority, for he had that high integrity which prevented him from an expression of opinion without the knowledge research gave to him. It is noteworthy that he was on the Councils of the Newcomen Society and the English Association for many years and his loss will be felt deeply in many quarters.

The year 1928 was the centenary of the death of James Sadler, the first English aeronaut. It was Hodgson who, that year, rescued Sadler's name from comparative obscurity and persuaded many of his friends, as Honorary Librarian of the Society, to subscribe to a memorial tablet to Sadler in St. Peter's Church, Oxford, in which city Sadler was born. Hodgson's lecture on 21st March 1928 on James Sadler, Aeronaut, Chemist, Engineer and Inventor, was not only a tribute to Sadler but an unconscious one to the lecturer himself.

Those who visited the International Aero Exhibition at Olympia in July 1929 will remember the remarkable exhibit of historical books, engravings, MSS., and other aeronautical items, prepared and arranged by Hodgson on behalf of the Society. He not only wrote most of the descriptions, but provided the greater part

of the old aeronautical prints and rare books which were shown. Many of them were afterwards exhibited in Berlin.

During the 1914-18 War Hodgson bought the astonishing collection of John Cuthbert, dating from 1820, of old balloon prints and posters, to which he added considerably. Though tempted by high offers from America he accepted an offer in 1947 from Sir Frederick Handley Page when he learnt that it was the intention of Sir Frederick to present the collection to the Society, where Hodgson had always hoped it might find a permanent home. The collection is now one of the Society's prized possessions.

In 1933 there was published by the Newcomen Society, the *Note Book of Sir George Cayley*, with an introduction by Hodgson. On 6th January 1936 he lectured before the Royal Aeronautical Society on "The Founder of British Aeronautical Science."

In that lecture on Cayley he said, "I fully realise that to those working in the full flood of present day problems and practice, matters historical are apt to be disregarded as of no practical interest or value. That, I would venture to suggest, is not a wise view—on the contrary we cannot afford to ignore the lessons that history and experience of the past teach. Moreover, to disregard them is to lose the inspiration and encouragement which come from knowledge, however slight, of the problems and difficulties which beset the great pioneers of the past, and the manner in which they overcame them."

It is fitting in this age of an "I couldn't care less" attitude among so many, that Hodgson's words should be recalled and recorded afresh.

The year 1943 was the centenary of W. S. Henson and in the April JOURNAL of the Society of that year Hodgson contributed a paper on the "Aerial Steam Carriage" of 1843.

During the last twelve months of his life Hodgson was working on a life of Sir George Cayley as well as working on a catalogue of some Johnsoniana. At Scarborough, in 1951, much of the success of the Exhibition held there in memory of Cayley, was due to Hodgson's help and advice.

Hodgson's reputation is high and safe in many directions. He had those virtues which are becoming rarer as civilization becomes more common, loyalty, idealism, humility and utter integrity of mind and action. He attracted friends from the highest to the lowest, for he could "walk with kings and keep the common touch." His very qualities misled many as to the inner greatness of the man. With them all he was passionately fond of good music, and had a knowledge of boxing and athletics generally which would have enabled him to hold his own in sporting company. He was, too, an ardent cricket and rugger enthusiast.

Hodgson was proud of being a President of the Johnson Club and for long was its Honorary Treasurer. He became a trustee, at the suggestion of Lord Harmsworth, of Johnson's House in Gough Square, an honour which gave him great personal satisfaction as a learned Johnsonian.

In the *London Mercury* for May 1924 he wrote a paper entitled "Johnson on Ballooning and Flight."

Earlier in this memoir it was said that Hodgson was learned in literature. One may fittingly conclude, therefore, with two quotations, one of which he used himself in his talk before the Society in 1926. It is from the Johnson he loved so well. "I will be conquered. I will not capitulate," and the other is from Edmund Burke, written towards the end of the 18th century,

"These gentle historians dip their pens in nothing but the milk of human kindness."

That was John Hodgson, Honorary Fellow of this Society.

J. LAURENCE PRITCHARD.

Lieut.-Col. W. LOCKWOOD MARSH writes:—

I should like to pay a personal tribute to John Hodgson in the JOURNAL, since I was instrumental in his becoming Honorary Librarian of the Society.

I first met him in 1918 through Air Commodore Maitland with whom I shared a passion for old books on aeronautics, a subject on which Hodgson was of course, by profession, an expert. Thereafter we met frequently and during the preparation of his *History of Aeronautics in Great Britain* we were in constant touch. Indeed, he honoured me by allowing me to read much of it before publication both in manuscript and proof.

Particularly impressive, I think, was the soundness of his judgment in appraising the work of the various early experimenters despite at the outset his complete lack of any technical knowledge of aeronautics whatever. The appearance of his book was a major event in aeronautics, and indeed in literature, since it set a standard and provided a classic example of what a work of that nature should be; not least in the truly magnificent index, to the form of which he gave much thought.

I shall never forget his delight and modest pride when he became the owner of the famous Cuthbert collection, the almost legendary assembly of prints whose continued existence was for long uncertain and its whereabouts unknown. He devoted much anxious consideration to the problem of its future home and was greatly relieved when, owing to the modest value he was willing to put on it, it came to rest with the Society where it is to be hoped it will remain in perpetuity.

My most treasured memory of him is of our spending a week together in Paris, whither with characteristic generosity he accompanied me to help in the selection of prints for reproduction in my own *Aeronautical Prints and Drawings*. During this week we agreed which prints we should each reproduce in our respective books so as to avoid needless repetition. In the course of it we visited under the expert guidance of Mr. Charles Dollfus every known collection of prints and drawings and paid a pious pilgrimage to the sites of the early balloon ascents. With such a companion all this was a quite unforgettable experience.

John Hodgson was in the widest sense a truly good man. He possessed a simplicity and pureness of spirit which will keep his memory for ever green in the minds of all who knew him. It was this quality which made him, as he was, so beloved of children. He was indeed a most lovable man.

THE FIFTH LOUIS BLERIOT LECTURE

The Future of the Flying Boat

by

HENRY KNOWLER, A.M.I.C.E., F.R.Ae.S.

The Fifth Louis Blériot Lecture was given in Paris at the Société des Anciens Elèves Ingénieurs Arts et Métieres, Avenue d'Iéna, on the 12th March 1952, under the auspices of the Association Française des Ingénieurs et Techniciens de l'Aéronautique, by Mr. Henry Knowler, A.M.I.C.E., F.R.Ae.S.

The Lecture was attended by several members of Council of the Royal Aeronautical Society and by the Secretary, Dr. A. M. Ballantyne, T.D., A.F.R.Ae.S., as well as by a number of members of the Society and the British Aircraft Industry.

Monsieur Jules Jarry, President of A.F.I.T.A., presided and welcomed the visitors. He regretted the absence of the President of the Society, Major F. B. Halford, C.B.E., F.R.Ae.S., and on behalf of members of A.F.I.T.A. hoped that he would soon have fully recovered his health. He welcomed particularly Air Commodore F. R. Banks, C.B., O.B.E., F.R.Ae.S., who deputised for the President, not only because he was a friend of A.F.I.T.A.'s but because he had given the First Louis Blériot Lecture.

Air Commodore Banks, speaking in French, conveyed the sincere regrets of the President whose health prevented him from being present, his best wishes for the success of the Lecture and for the prosperity of A.F.I.T.A. and the continuation of the happy relations between A.F.I.T.A. and the Royal Aeronautical Society. He then introduced the Lecturer, Mr. Henry Knowler, Head of Research and a Director of Saunders-Roe Ltd.

Mr. Knowler, also speaking in French, expressed his regret at his inability to read his lecture in French and his gratitude to Monsieur Benoit for doing so on his behalf.

The Lecture was then read by Monsieur Benoit, Administrative Adviser of O.N.E.R.A.

1. THE PAST

Louis Blériot's epic first flight across the Channel in 1909 was the inspiring inception to a new era of travel. Man's imagination was stirred by the fact that a tiny aeroplane had crossed the sea barrier, thus showing to the least thoughtful that no longer were oceans an obstacle to international communication.

With the subsequent rapid development of aviation the Channel crossing became a matter of course, but it was nine years before a long ocean crossing was made, when, in 1918, Alcock and Brown flew a Vickers Vimy from Newfoundland to Ireland, and it was thirteen years before Lindbergh again captured the world's imagination by his lone flight across the Atlantic.

There is no doubt of the value of pioneer flights such as these in stimulating aircraft development towards greater performance, reliability and suitability. Engineers, from the earliest years of flying, have reacted from the risks which were accepted by the pioneers, and have continually striven to eliminate the cause of mechanical and structural failure, and to alleviate the consequences.

The subject of this lecture is the future of the flying boat, but it is necessary to approach it from the past and to base it on present achievement and, although no attempt is made to give a history of seaplanes, the main outline developments are reviewed.

Some of the first pioneers, no doubt because of the difficulty of obtaining the uninterrupted use of suitable flying fields, designed floats for their aeroplanes, and flew from the waters of rivers or lakes. These were the contemporaries of Louis Blériot, and it is interesting to note that it was a Frenchman, Henri Fabre, who in 1910 first flew an aircraft from the water.

About the same time the idea of a boat with wings occurred to Glenn Curtiss, in America, but it was not until 1911 that he built and flew a biplane which is recorded as being the first flying boat.

The First World War accelerated the development of all types of aircraft. Due to the imagination of Commander John Porte, who was in command of Royal Naval Air Service development work at Felixstowe, the flying boat made a big advance, taking its place as an accepted military operational type, and in the lead of aircraft in point of size. The aircraft built are well known as "F" boats, and were used for regular patrol flights over the North Sea against German U-boats.

In the years immediately after, in spite of severe curtailment in expenditure, the obvious advantages of the flying boat for long-distance flying, and its capability of independent operation, helped to maintain a steady development. The progress made from time to time was demonstrated by a number of long-distance cruises, exemplified by the formation flight, in 1927, of four Southampton flying boats from Plymouth to Sydney, Australia, and afterwards to Hong Kong: the total distance flown was 28,000 miles.

A further outstanding example of this type of operation was the flight, in 1933, of twenty-four Savoia F.55 flying boats, which flew in formation from Italy across the Atlantic to Chicago by way of Iceland and Labrador, returning by way of New York and the Azores.

These cruises, and many others, demonstrated the flying boats' capability of independent action, an attribute which was considered to be of military importance.

Throughout this period of roughly two decades, the flying boat developed in size, speed and particularly in range; machines attained a still-air performance of about 2,600 miles, and a maximum size of about 30,000 lb. With few exceptions the aircraft were biplanes, and only latterly had metal replaced wood in the hull construction.

This was the time of change to the universal use of monoplanes. The following decade saw big advances in flying boat design, with increase in size and improvement in efficiency. In America in 1933 Sikorsky, after producing several highly successful flying boats, showed with the S.42 that a relatively high wing-loading was acceptable provided that the power loading was reduced, and by this means cruising speeds were stepped up by 50 m.p.h.

Dornier had built a famous series of braced monoplane flying boats with sponson stabilising, culminating in 1930 with the Do.X, with a weight of 123,000 lb., an outstanding size at that time. These sponson flying boats of Dorniers were followed by Glenn Martin, with boats, similarly stabilised, designed to be suitable for trans-ocean flights. These were the famous Martin Clippers which operated regular services across the Pacific from 1936 to the outbreak of war. In 1935, Short Bros. Ltd. produced their famous Empire flying boat—a type which, in various developments, has persisted up to the present time.

In their day these flying boats were the most efficient transport aircraft available, and this enabled Pan American Airlines and Imperial Airways to pioneer the great international overseas air routes.

In the period immediately preceding the Second World War, and later, the established suitability of flying boats for trans-ocean flight prompted the design of a number of aircraft of greatly increased size. Among these were the Martin Mars of 165,000 lb. which is still operating as a U.S. Navy transport in the Pacific, the Shetland of 125,000 lb. built by Saunders-Roe and Short Bros. in collaboration, and the Howard-Hughes of 450,000 lb.

In France there has always been considerable enthusiasm for flying boats, and a steady development has taken place parallel with and, at times, in advance of, the aircraft mentioned. Breguet, C.A.M.S., Latécoère, S.N.C.A.S.E., among others have produced large flying boats which were often ahead of current size and which won numerous records for distance and high payloads.

One of the largest of these—the Latécoère 631—visited England in 1947, when it was flown over London and gave a large number of passenger flights. This machine, weighing 165,000 lb., was fitted with six 1,600 h.p. Cyclone engines, which gave it a cruising speed of 185 m.p.h. It was fitted to carry 70 passengers and had a still-air range of 4,600 miles.

Another of these large flying boats was the S.N.C.A. Sud'est 200, weighing 159,000 lb., engined with six 1,600 h.p. Gnome Rhône 14 R's, which was designed to carry 80 passengers and had a range of 4,400 miles.

During these three decades the hull form had remained substantially the same (Fig. 1). This included a transverse main step a little aft of the c.g. and a second step situated well aft. In the course of time the second step was gradually reduced in width until finally the aft planing bottom terminated in a point.

In early developments a change of angle between the fore and aft planing bottoms had been found to be necessary, and this has persisted up to the present time. An angle of about 8° is usual but 5° to 11° have been used.

The main step is the major cause of the increased drag of a hull over that of the streamline body. Early attempts to eliminate the step altogether proved unsuccessful, as the suction on the aft bottom prevented the aircraft from leaving the water, and reduction in depth usually proved unsuccessful since it led to fore-and-aft instability.

When larger aircraft were built the planing bottom loading was allowed to increase, but this was found to cause instability unless the depth of the main step was also increased and, until recently, it has been found necessary to make this about 8 per cent. of the maximum beam.

Other hull features which have persisted to the present time are the heavy turn-down of the bow chine in order to deflect spray, and the retention of a sharp chine throughout the length of the planing bottom.

Throughout this period, which ends shortly before the Second World War, flying boats were in advance of landplanes in size and also in their attainment of range. However, as a consequence of the large size of hull necessary firstly for buoyancy and secondly in order to raise the wing and propellers above waves and heavy spray—and of the high drag associated with the contemporary boat form—the speeds attained fell behind those of landplanes.

This brief review would not be complete without reference to the Schneider Trophy

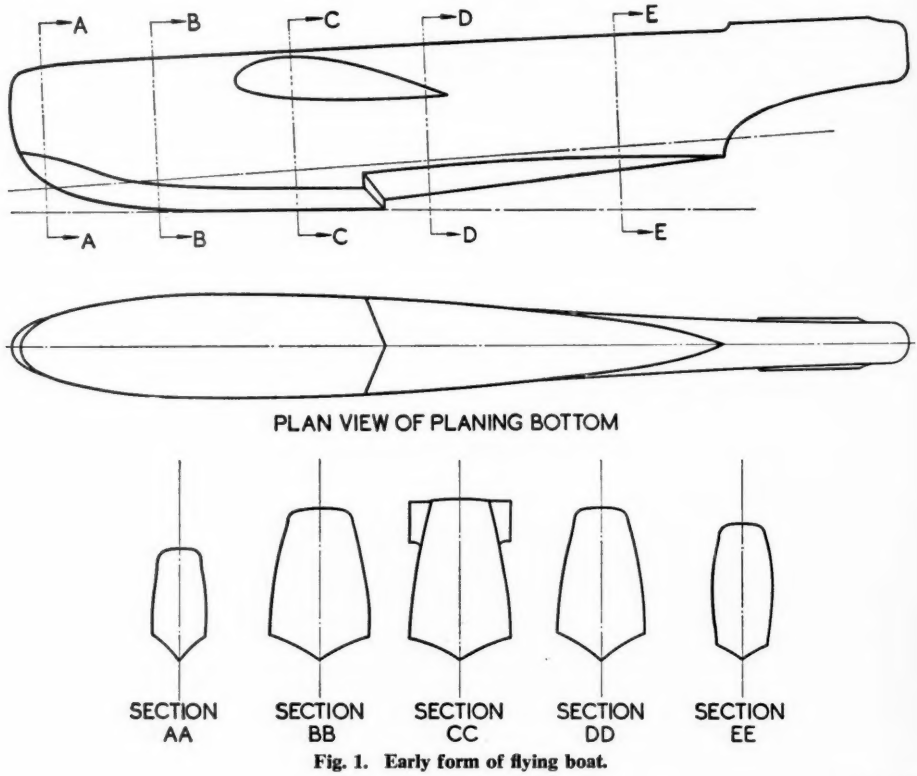

Fig. 1. Early form of flying boat.

Fig. 2. The Martin Marlin.

racers. The aircraft taking part in the races were seaplanes and, in their time, were the fastest aircraft in the world. These were the forerunners of what was probably the most notable fighter in the Second World War, the Spitfire. The Schneider machines demonstrated the possibility of building high speed water-based fighters—a subject to be discussed later.

2. THE PRESENT

It is thought that the foregoing review is sufficient to show earlier trends in flying boat design. This next section begins with a description of, and discussion on, representative contemporary types before turning to recent technical development.

2.1. CONTEMPORARY TYPES OF FLYING BOATS

2.1.1. *Ocean patrol boats*

These flying boats are required for operation from areas which, because of the lack of aerodromes, are not suitable for landplanes or, for other reasons, are required to operate from a marine base.

Their primary duty is submarine search but they are also used for location of enemy

Fig. 3. The Convair XP5Y.

transports and their destruction, convoy escort, the shadowing of enemy ships, air-sea rescue and so on. For these purposes long endurance, coupled with a large radius of action, is required. For search or convoy escort a slow speed at a relatively low altitude is necessary, although high cruising speed out to the scene of action is also desirable.

The various duties of piloting, navigation, search and protection, call for a relatively large crew. During the Second World War, long patrols were carried out successfully by single crews, an instance being the Convair Catalina, which shadowed the battleship *Bismarck* before its destruction. This patrol lasted more than thirty hours, but modern equipment places a greater strain on the individual, and double crews may be advisable for flying boats which have exceptionally long endurance.

The requirements enumerated call for some degree of compromise, added to which is the necessity for a high standard of seaworthiness, so that the aircraft can alight on the open sea. Modern examples of this type of flying boat are the Glenn Martin Marlin P5M-1 and the Convair XP5Y-1.

The Marlin, shown in Fig. 2, is a twin-engined flying boat derived from the Martin Mariner and well illustrates the aerodynamic compromise necessary to meet the exacting requirements for ocean patrol aircraft. The hull form shows a big advance on previous types. The main step is shallow, tapered in plan and partly faired, and the aft planing bottom is prolonged to terminate at the stern post. The fixed lateral floats will be noticed. The high position of wing and engine nacelles is typical. The fairing behind the nacelles is used to house the bomb load.

The Convair XP5Y patrol bomber flying boat, shown in Fig. 3, embodies many new features which exemplify the modern trend. The aircraft weighs 138,000 lb. but can carry a considerable overload. It is fitted with four Allison T.40 coupled turbines, driving contra-rotating propellers, with a total equivalent horsepower of 22,000.

The aircraft has been designed for ocean patrol, for which long range is necessary, but because of its low power loading it has, for this type of aircraft, an unusually high speed, being credited with a top speed of 390 m.p.h.

This flying boat is the first example of hull design in which increased fineness ratio has been used. This principle will be referred to later in discussing new technical developments.

2.1.2. *Civil flying boats*

In discussing current examples of the civil flying boat it is hardly necessary to recall the honoured place, in passenger transport development, in which the Short Empire Boat stands. These machines were known as the Short C Class Boats. Although the original design dates back to 1935, derivatives are still in operation over various air routes and have only recently been withdrawn from the England-Australia and England-South Africa services of the British Overseas Airways Corporation. During the operational life of the type the fleet mileage totalled over forty million miles.

The contemporary type, the Solent IV, is somewhat larger than the C Class, and has a

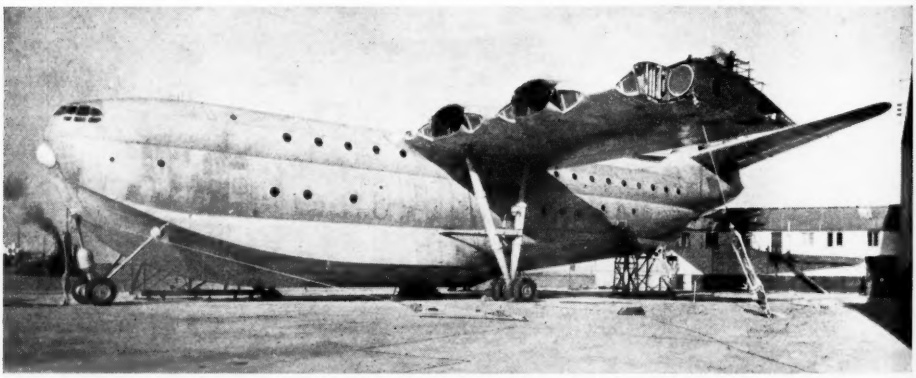

Fig. 4. The Saunders-Roe Princess.

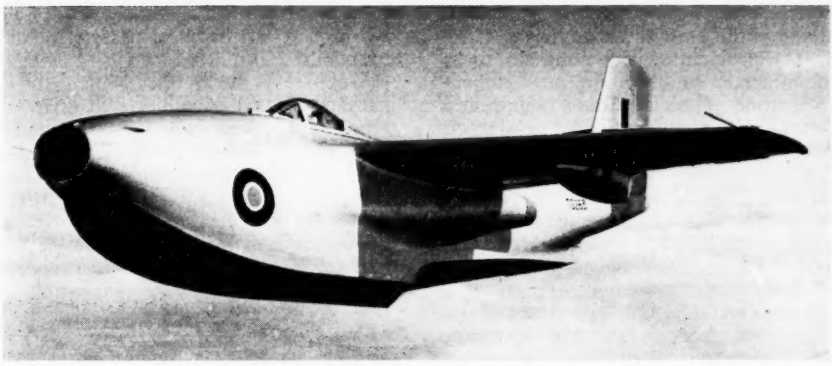

Fig. 5. The Saunders-Roe SR/A1.

total weight of 79,000 lb. It carries 10,000 lb. payload with a still-air range of 2,400 nautical miles.

At this time the Solent is the only modern flying boat on scheduled flights, but a new civil flying boat is now being built, and will be completed shortly. This is the Saunders-Roe Princess, the first of which is now nearing completion, and in a year or so three of this type will be handed over to the operators.

The design of this flying boat sums up the state of development at this time (Fig. 4). It is large, having a take-off weight of 330,000 lb., and is fitted with ten propeller-turbine engines of a total equivalent horsepower of 35,000, estimated to give it a high cruising speed of 380 m.p.h. at 40,000 ft.

The cross section of the hull, for pressurising reasons, is a figure eight; consequently the cabin space is arranged on two decks. This layout has proved the best compromise to meet the requirements of passenger comfort, propeller height above the water and low expenditure of weight in pressurising. This is the first flying boat hull to be pressurised, a working pressure of 8 lb./in.^{2} being provided. The design range is 5,000 miles when carrying 105 passengers.

The hull design embodies a number of new features. The main step, in plan, is semi-elliptical, and the aft bottom is faired away directly from the step without a break in depth. This has resulted in a useful reduction in air drag, while providing one of the most stable hull models so far tank-tested.

The use of an aircraft of this size has resulted in a high degree of comfort for the passengers. A number of two-berth cabins have been provided as well as fully-reclining seats, and the layout includes lounge bars, four dressing rooms and two galleys.

2.1.3. *Water-based fighters*

It is easy to understand how the necessity for mounting the propeller and engine high above the water, and the requirements of buoyancy for the hull have, until recently, prevented the design of a small, aerodynamically clean flying boat. Hence, it has not been possible to build a satisfactory water-based fighter, except perhaps in float form.

With the advent of the jet engine these restrictions have been removed, and a new type of fighter has become possible. The first and only example so far built is the Saunders-Roe S.R./A1 (Fig. 5). This aircraft was first flown in 1947, the design having been started at the end of the war, and for this reason it does not include the more recent developments in flying boat form which have made possible a further considerable reduction in drag.

The SR/A1 weighs 15,000 lb., and is fitted with a pair of early type axial-flow jet engines, manufactured by Metropolitan Vickers. The armament consists of four 20 mm. cannon. The aircraft was designed to a specification which included cockpit pressurising, heating and pilot ejection. The low-drag-section wing is fitted with pressurised integral fuel tanks.

2.1.4. *Amphibians*

An aircraft which can operate from both land and water has obvious advantages and

consequently there has been a large number of notable examples of this type of flying boat. The problem of producing a successful amphibian is probably the most difficult one in aviation. The aircraft is a compromise throughout, as it attempts to be a satisfactory landplane while meeting the stringent requirements of the flying boat. Nevertheless, there is a steady demand for amphibians which are necessary to meet the exigencies of situations where other types of aircraft are unsuited. For inter-island traffic, forestry patrol and river communications, naval communications and air-sea rescue, the amphibian is ideal and is the best, and possibly the only, solution.

In general, amphibians are small, although a fairly large version, the amphibious Catalina weighing 33,000 lb., was operated in the Second World War.

Probably the best example of the naval communication and air-sea rescue type, although not the most recent, was the Vickers Supermarine Walrus, and its later version, the Sea Otter. Large numbers of these amphibians were in use during the Second World War and, being exceptionally seaworthy, they were found to be very suitable for their work of air-sea rescue. The Walrus was fitted with Bristol Pegasus engines. The take-off weight was 7,200 lb. and the speed 135 m.p.h.

A recent example of the civil type of amphibian is the Short Sealand (Fig. 6). This is a passenger-carrying machine, suitable for inter-island traffic and river communication. It weighs 9,100 lb. and is fitted with two de Havilland Gypsy Queen engines. It carries seven passengers and has a range of 220 miles.

Amphibians are frequently used for coast-guard work and in addition to their normal duties are often called upon to render assistance to vessels in distress. This may have to be done when wind and sea conditions are adverse; therefore, an adaptation of a medium-sized flying boat is sometimes used in which retractable wheels, used for beaching only, are incorporated in the design.

2.2. New Technical Developments

2.2.1. *Air drag*

The high air drag of flying boats relative to landplanes, reference to which has already been made, is not inherent in the type, although it must be admitted that, up to and during the Second World War, flying-boat hulls were poor aerodynamically. In recent years the primary aim in development has been to reduce or eliminate this drag difference so that flying boats can compete on equal terms with the corresponding landplane.

The first step taken was to analyse the factors contributing to the increased drag of a hull over that of a basic streamline. In this connection it is recalled that the conventional hull originally included distortion of the basic streamline form in order to lift the tail clear of the water, a deep main step, a rear step, chines and keel. The fineness ratio of these

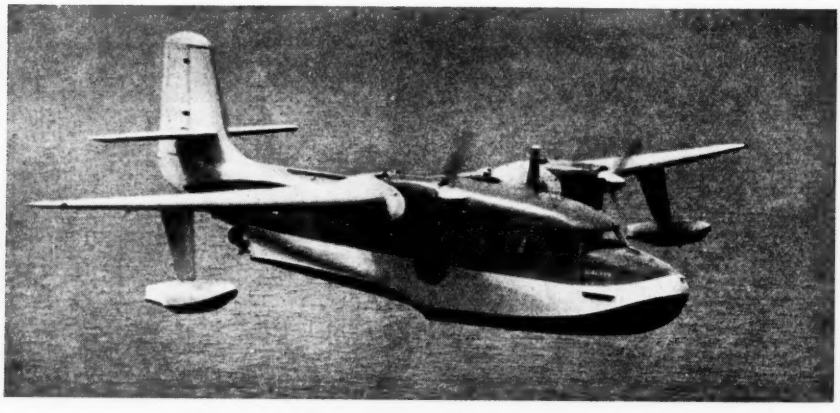

Fig. 6. The Short Sealand.

hulls was between 6 and 7, with a forebody length/beam ratio of approximately 3 (Fig. 7(*a*)).

The basic streamline form of reference was a body of revolution based on the shape of the airship R.101. On this basis of comparison it was found that contemporary hulls had a relative drag factor k of 1.43 to 1.51. A number of wind-tunnel tests were done at high Reynolds numbers on representative hull bodies, in which the drag contribution of each of the items just mentioned was measured. The following extracts summarise the information derived from two sources:—

(1) Tests carried out at a Reynolds number of 17×10^6, by the N.A.C.A. in America, on a flying-boat form with deep flat-sided hull with a fineness ratio of 9, gave the following results:—

	k
Basic body of revolution	1.00
Hull completely faired	1.08
Planing bottoms added, chines rounded	1.25
Hull with squared step and chines	1.43
Hull with squared step and chines, but with bow chines rounded	1.35

(2) Tests made by the National Physical Laboratory at a Reynolds number of 40×10^6, on a hull based on circular form, of fineness ratio 7, representative of a refined form of hull, gave the following:—

	k
Body of revolution	1.00
Camber to body	1.03
(Basic fuselage with fin and cabin)	1.05
Planing bottoms, chines and keel added	1.13
Hull, complete with steps	1.51

Considering these tests, together with certain additional information available, the analysis of drag increments for a typical hull of the form used during the Second World War was as follows, stated as a percentage increase in drag relative to a body of revolution:—

	Percentage increase
Cambering the basic streamline	3 to 5
Adding fin and cabin	2 to 3
Adding fore and aft planing bottoms	8 to 9
Squaring the mid-body chines	1
Turning down of bow chine	1 to 8
Addition of main step	20 to 38

It will be noticed from these percentages that the most serious cause of drag is the main step, although a badly shaped bow can also contribute seriously to the increase, but the case quoted is not typical and the lower percentage is more appropriate to current practice. It is natural, therefore, that reduction of the air drag of the main step has been the primary target in recent investigations.

The purpose served by the step is to break the water flow over the bottom of the hull at a point approximately where the normal pressure from the water diminishes and farther aft changes to suction. This suction, if allowed to persist, besides increasing the load to be lifted from the water, is a potent cause of porpoising during the taxi run. A hull without a main step cannot leave the water because of this suction and it is necessary, therefore, not only suddenly to terminate the water pressure in the step region but to supply adequate air ventilation, in order to prevent the spray which leaves the step from rising and clinging to the aft planing bottom (Fig. 7(*a*)).

A step which retracts in flight (*see* Fig. 7(*b*)) is an obvious solution to the problem of drag reduction, and this has been tried, but the weight and difficulty of maintenance have ruled it out as a practical proposition.

Another solution used with considerable success has been to add fairing behind the main step (*see* Fig. 7(*c*)). This can be done in two ways, either by fairing in elevation alone or combining the fairing in elevation and plan. The drag of transverse steps, having straight fairings in elevation, decreases appreciably with fairing ratios above 3, the optimum fairing ratio being 9. At this optimum value the total hull drag is approximately 20 per cent. above that of the basic body of revolution under conditions of minimum drag. With these long straight fairings the natural ventilation of air along the break of the step must be supplied by other means. A method of doing this is to ventilate through air ducts to slots in the region of the step and with additional air ventilation slots some way down the aft planing bottom. Concave fairings have proved to be inferior to straight fairings and, while convex fairings are an improvement aerodynamically, they are unsuitable for hydrodynamic reasons.

Applying the fairings with tape in plan, as well as elevation (*see* Fig. 7(*e*)) further improves the drag and, as the included angle

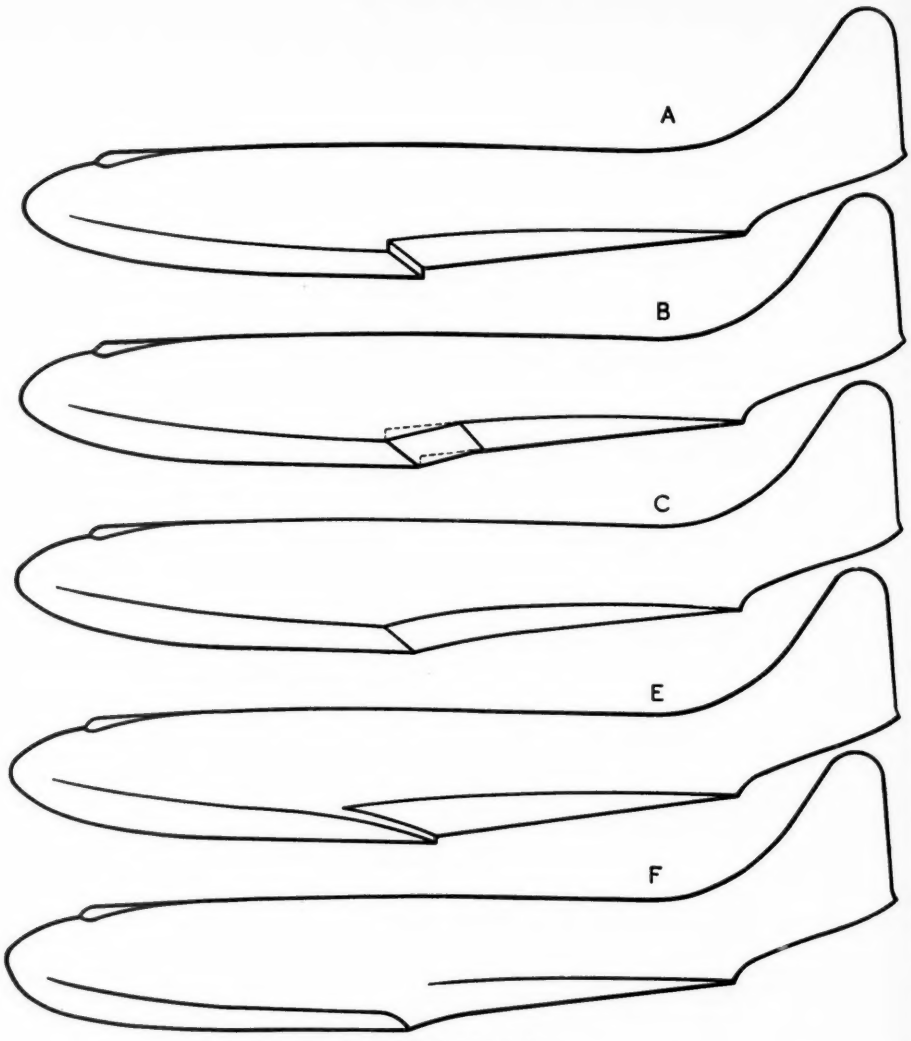

Fig. 7. Flying boat steps.

of V is reduced, the drag due to the step decreases and virtually disappears when the angle is 10°. Unfortunately, satisfactory hydrodynamic properties have not so far been associated with small angles of V.

A compromise in hull step fairing has been applied to the Saunders-Roe Princess (Fig. 7(*f*)). This has a 6 : 1 fairing, springing from a semi-circular break in the bottom lines. The drag of this hull is approximately 15 per cent. greater than that of the basic body of revolution.

Fairings of greater length have been tested up to ratios of 20 or more, and forced as well as natural ventilation has been used in order to overcome instability troubles. These were full-scale tests, and had some measure of success, but the improvement in air drag was small and hardly worth the trouble and weight involved in providing special forms of

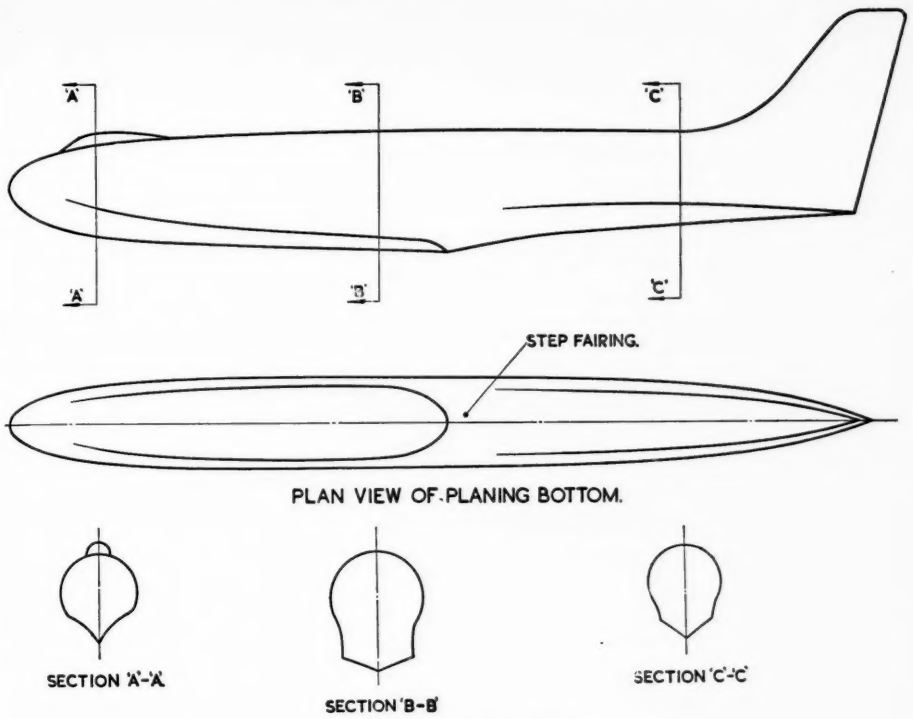

Fig. 8. A refined hull form.

ventilation. The latter test naturally suggested the elimination of the step altogether by the use of forced ventilation, and a certain amount of preliminary work has been done in the testing tank on this idea, giving encouragement to further research in this direction. In a recent series of tank tests it was shown that a deflection of $7\frac{1}{2}$ per cent. of the jet engine compressor delivery to a suitable pattern of air jets below a streamline body caused the body to run stably at satisfactory attitude and resistance.

Recently, extensive research has been done on the effect of varying the fineness ratio of the hull. Accepted practice in this respect has been to make the forward planing bottom length 3 to $3\frac{1}{2}$ times the maximum beam, corresponding to an overall length/beam ratio of six to seven.

Tank tests on a series of hulls of differing fineness ratio have led to the establishment of an empirical relationship connecting length and beam where, for equivalent hydrodynamic behaviour, $l^2 \times b = \text{constant}$. Therefore the length/beam ratio can be varied and the old conception of beam loading, based on $\Delta/(w \times b^3)$, which restricted loading for good behaviour within close limits, can now be discarded and very much higher loadings can be accepted provided that the length of the forward planing bottom follows the new relationship.

This important conception in hull loading has been presented as a method of drag reduction, but it is much more than this, since a free choice of length or beam is now possible, and the designer can tailor the hull to suit payload requirements, seating disposition, or the disposal of military equipment, without facing excessive volume or weight. This has encouraged the projected use of hulls of greater fineness ratio, with corresponding low beam. In this way the drag increment due to the step can be reduced. For example, by this means an increase in the forebody length/beam ratio from 3.5 to 6.5 results in a reduction in hull drag of 5 per cent.

Because of its large contribution to increased drag, the main step has been discussed at some length, but it is also possible to make improvements in the other factors which increase drag.

The basic streamline form can be chosen to suit the function of the aircraft, a high length/beam ratio being preferable (*see* Fig. 8). Depth of body will be decided, either by the internal disposal of payload or by the necessity for providing adequate clearance of the power plant from spray. In the latter connection, a jet engine layout is obviously more favourable than a power plant employing propellers. The planing bottoms, together with keel and chines, on the evidence of the drag analysis quoted, are responsible for about 9 per cent. increase in drag over the basic body. This figure can be reduced a little by carrying the aft bottom to the sternpost, and, at the same time, the cambering of the basic streamline can be reduced. By careful design in the bow, so that the chines follow the air flow pattern, the large increment of drag quoted in one of the sets of tests can be avoided. Alternatively, the drag cost for heavy bow turn-down can be eliminated completely by the use of spray plates which are retracted after take-off. It is also possible to make the mid-body chines follow the natural streamline flow for the mean cruising attitude. Finally, the step drag can be reduced to minor proportions by one of the methods discussed.

To summarise, model tests indicate that, without sacrificing hydrodynamic qualities, by the application of the various possible means of drag reduction, the basic drag of the ideal streamline body need not be increased more than 10 to 12 per cent. in converting it to a suitable hull form. This cost in drag can be compared with approximately 4 to 5 per cent. increase which must be accepted for a typical landplane fuselage.

2.2.2. *Water resistance*

The resistance during the take-off of a flying boat is the sum of quantities due to air drag, wave-making resistance, planing resistance and skin friction. This is shown in Fig. 9.

Air drag is similar to that for a landplane take-off, the drag of the landplane including the resistance of the extended chassis. The wave-making resistance is self-explanatory; it is greatest during the early part of the take-off but, being proportional to displacement, it reduces as the wing lift increases, and is of low value beyond the "hump." Planing resistance varies with (speed)^2 and is directly proportional to area and attitude; it is, in fact, the resistance component of the hydrodynamic normal force on the planing bottom. The last item is skin friction. The diagram illustrates the proportions of these quantities but it will be noticed that no firm line of demarcation has been shown between wave-making and planing resistance; this is due to the virtual impossibility of separating these two qualities.

Because of the inter-action of the various components of the resistance, a change, benefiting one item, will almost certainly have a detrimental effect on the others; therefore,

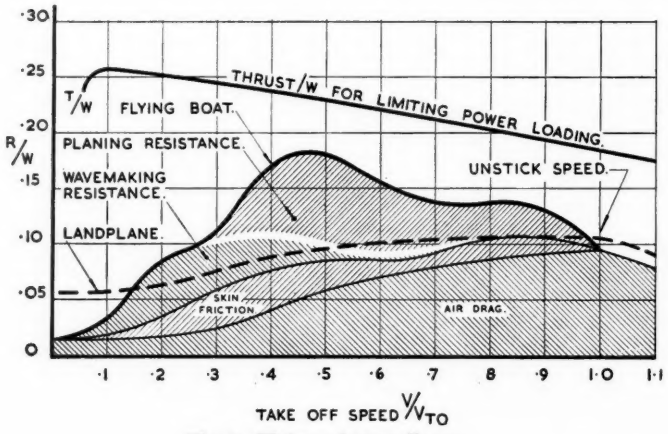

Fig. 9. Water resistance diagram.

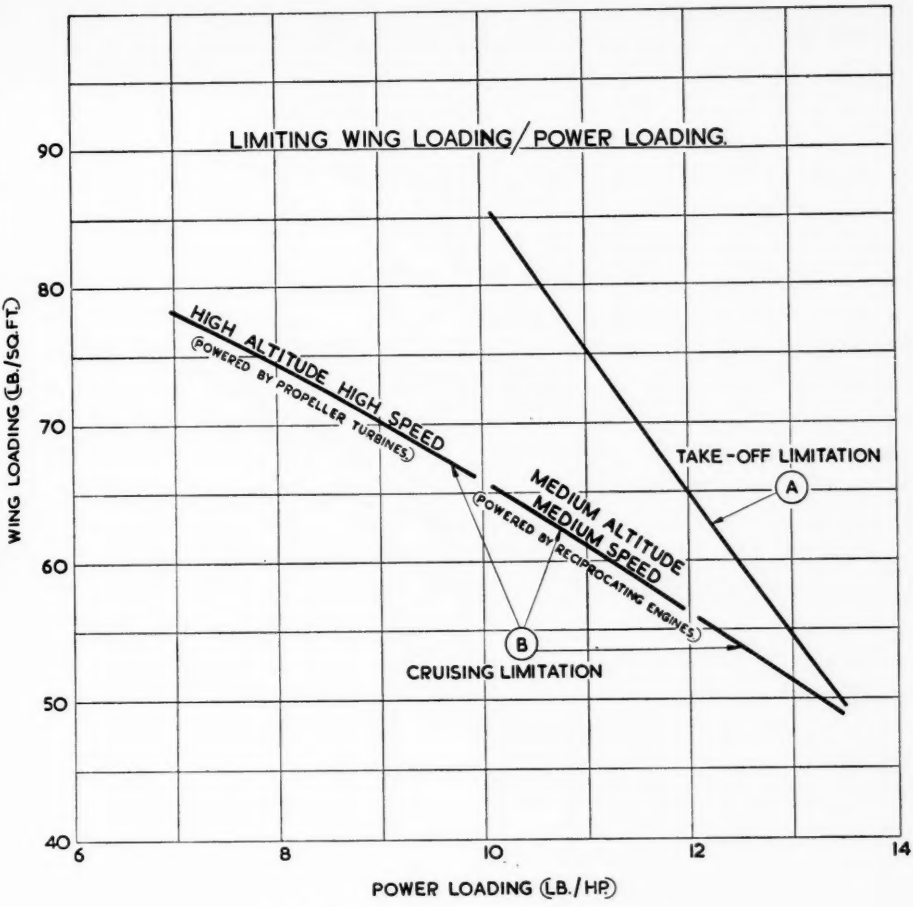

Fig. 10. Wing and power loading limitations.

the modern flying boat hull tends to be a well-balanced compromise. At present a refined form of flying boat has a resistance, R/W, of 0.18. This figure is for an advanced stage of development and it is not expected that further important reductions can be made, at least with a conventional type of hull.

It is quite easy, however, for the resistance components to increase. For example, the skin friction component can be changed considerably by the impact of spray, and if negative pressure is allowed to build up on the aft planing bottom the hull may ride at inefficient attitudes and additional lift is required to balance the downward suction.

The take-off drag of a landplane is shown in Fig. 9 for comparison. This is the sum of the air drag and the resistance due to the rolling friction of the wheels. It will be seen that the flying boat suffers from some disadvantage in respect of take-off power requirements. It can be said generally that the power loading of a flying boat is limited by the resistance at the hump speed, whereas the landplane loading is limited by the runway length. This tends to limit the flying boat's loading and, since the reserve thrust for acceleration at the hump has been found in practice to be unsatisfactory if reduced below 0.05 g, the hump power limitation tends to be a design criterion for flying boats

designed for range or load rather than performance. The engine type has an important effect on this situation. For example, propeller turbines obtain their best efficiency at high speed and altitude and, therefore, medium power loadings show the best efficiency. On the other hand, reciprocating-engined aircraft give longest range at low altitude and medium speed and in this case high power loadings give the best results. With piston engines, assistance at take-off has been found to be of considerable benefit.

Figure 10 illustrates this situation more clearly. Here the limiting power and associated wing loading are shown for various conditions of design. For example, the limitation imposed by the take-off requirement is shown in Curve A, whereas the loading requirement for cruising with either piston or turbine engines suitable for a passenger transport, is shown in Curve B. Another limiting factor on power/wing loading may be the cut-engine case after take-off, and with four-engined aircraft this usually over-rides the take-off limitation.

Hydrofoils

Improvement in the hydrodynamic lift of flying boat hulls has been subject to considerable research, and work is still being done to this end, since the lowering of the hump drag can pay high dividends. One method explored has been the use of hydrofoils. It is well known that high efficiencies, of the order of 30 : 1 lift/drag ratio, can be obtained with hydrofoils operating in optimum conditions. By the use of such lifting surfaces it should be possible to provide additional lift at low speeds for low cost in resistance, thus improving the overall efficiency. Investigations show that R/W of the order of 0.12 should be possible at the hump speed compared with the figure already quoted for the refined hull of 0.18.

There is a considerable background of knowledge on this subject, based on towing-tank investigations, as well as information resulting from experiments with seaplanes and surface craft, but there are many difficulties to be overcome before the application of hydrofoils can be successful. Although under favourable conditions the hydrofoil behaves in a similar manner to an aerofoil, an excessive rise in suction over the back of the foil, due to speed, attitude or loading, results in cavitation. Furthermore, breakdown of efficient lift may be precipitated by proximity of the foil to the water surface. It is difficult, therefore, to ensure stable running conditions, particularly when two systems of hydrofoils are used.

The most successful experiments have included two sets of foils, one at the bow and the other—the main lifting foils—just aft of the c.g. "Ladder" systems which may include pronounced dihedral have also been used. In their application to a flying boat, a possible solution is to use hydrofoil lift up to medium speeds and after they cavitate to use the planing lift from the lower surfaces. Subsequently the foils would retract completely into the streamline body.

The subject is worthy of further research because of the advantages offered in reducing both air drag and water resistance.

Hydro-skis

Somewhat allied to the hydrofoil is the hydro-ski. These obtain their lift from the water pressure on their lower surface in a similar manner to the planing lift of the boat planing bottom, but a considerably higher loading can be used and in consequence a higher attitude of the planing surfaces is necessary. The efficiency is poor compared with a normal boat form but the system has the advantage that complete retraction into a streamline body is relatively simple.

This is a comparatively recent development but considerable research has already been done, both in England and America, in which the application of hydro-skis to high-speed designs has been investigated. These have shown that it is possible to have a highly stable hydro-ski system which is capable of lifting an aircraft body off the water at relatively low speed. The hydrodynamic efficiency of a hydro-ski is low and it is unlikely that a lower figure for R/W than 0.35 can be obtained. However, because of their capability of total retraction, hydro-skis are very suitable for water-based fighters where high R/W is of little consequence, since the power available is more than adequate to ensure a short take-off run.

2.2.3. *Spray height*

Probably the most important factor in determining the general configuration of a flying boat is the propagation of spray (Fig. 11). This occurs in two forms; that emanating from the forward contact of the planing bottom with the water surface,

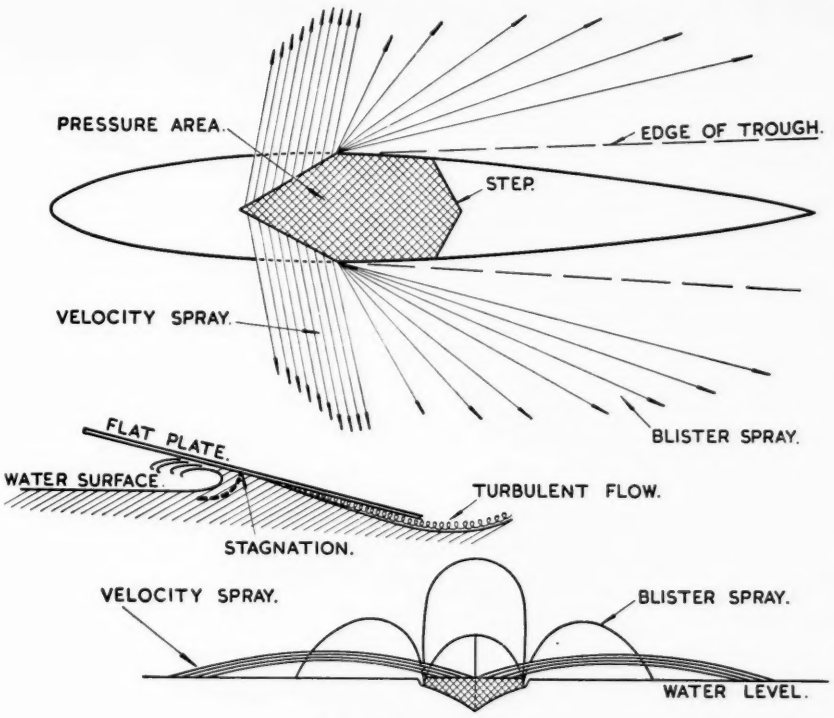

Fig. 11. Spray diagram.

ribbon spray, and the heavier form of spray called the "blister," which leaves the chine at its point of contact with the water. Both forms of spray are due to the peak pressure developed in the stagnation area where the planing bottom intersects the solid water. Ribbon spray is fairly light and although it may cause inconvenience in misting up the windscreen and so on, it has no damaging effect on the structure, and since it first travels forward over the bottom surface it can be directed downward by curvature below the bow chine. On the other hand, the blister spray has free release laterally and rises in a hollow cone of heavy spray. The height to which it rises determines the relative position of the propeller tips and, in some cases, the position of the wing and tail-plane above the water.

There are various methods of estimating spray height, but perhaps the most successful is that based on the results of tests, made in America, on a series of hulls having varying length/beam ratios and deadrise angles. Analysis of these and other results have made it possible to produce curves, based on spray heights, from which the propeller tip heights, necessary for satisfactory operation, can be determined.

During investigations it was realised that, in defining the load coefficient, more consideration must be given to the hull length than hitherto. Previously the load coefficient $C_\Delta = \Delta/(wb^3)$ did not include the length of the planing surfaces, but the American test results showed that hulls of varying length/beam ratio will have equivalent resistance and spray characteristics if a load coefficient $K = \Delta/(wl^2b)$ is used. The following points have been noted by various observers:—

(*i*) When Δ is constant, spray height decreases if either b or l are increased; l is more powerful because it occurs squared in the parameter, whereas b is only to the first power. In particular

(*a*) If l/b is varied but the product l^2b remains constant, then the spray height remains nearly constant.

(*b*) If l/b is increased but lb remains constant, the spray height decreases, as can be seen from the relationship

$$l^2b = (lb)^{\frac{3}{2}}(l/b)^{\frac{1}{2}}$$

i.e. $l^2b = \text{constant} \times (l/b)^{\frac{1}{2}}$

(*ii*) Actually, in the neighbourhood of the propellers,

$$\text{spray height varies as } \frac{\Delta}{wl^{\frac{3}{2}}b^{\frac{1}{2}}}.$$

Thus (*i*) If l and b are constant the height is proportional to Δ.

(*ii*) If Δ and lb are constant, spray height varies as $(l/b)^{-\frac{1}{2}}$ (*i.e.* decreases as the l/b increases).

(*iii*) If Δ and l^2b are constant, spray height varies as $(l/b)^{-\frac{1}{8}}$ (*i.e.* improves very slightly as l/b increases).

Spray suppressors

Investigations to determine means of suppressing blister spray show that local curvature at the chine, which terminates horizontally, or nearly so, has practically no effect on spray height. Reflex curvature at the chine is found to increase the spray height. This is due to the greater force at which the spray impinges on the local water surface after leaving the chines. Transverse bottom sections which are hollowed from keel to chine are an improvement over straight bottom sections but since no satisfactory definition of this curvature exists, comparison of the relative merits of various amounts of curvature have not been made.

Spray strips or plates attached to the hull at the forebody chine have been investigated. Plates which project horizontally from the chine have no effect on spray height and setting the plates at small negative angles to the horizontal shows no benefit, but plates at about 90° have proved successful. This is probably due to air flowing down the hull sides and aerating the mass of water leaving the spray strip in a downward direction, resulting in the aerated mass impinging with less force than normal on the local free water surface; consequently the spray does not rise as high as normally.

Spray strips, parallel to the keel but at varying distances from the chine, have also been tried but are found to be less effective, the reduction in efficiency being proportional to their distance from the chine.

2.2.4. *Stability*

Longitudinal stability

Most flying boats in the past have shown some degree of fore-and-aft instability. This has been accepted, the experience of the pilot being relied upon to correct or check the onset of porpoising in its initial stages; furthermore, since the various phases of instability were local to a narrow range of speed, it was frequently found that the aircraft accelerated through the region without permitting time for porpoising to develop. With the advent of high loadings and increase in unstick speeds it soon became evident that any form of instability was unacceptable since it could become uncontrollable and the consequences were likely to be serious. Thus it became important to determine the various forms of instability and under what conditions they occur. This is done by tank-testing dynamic models of the aircraft and plotting the unstable trim angles on a chart of trim versus speed.

The types of longitudinal instability are roughly classed as porpoising, skipping and pattering.

Porpoising is a cyclic oscillation in pitch and heave and is the most dangerous type of instability, especially when it occurs at low trim angles. In various tanks, records of the oscillations have been made, analysis of which indicate that trim and heave are out of phase, with trim usually leading.

Two types of porpoising occur, as shown in Fig. 12, which is a plot of hull datum attitude against speed. The first type takes place at low trim angles and is known as "low angle" type porpoising. The other occurs at high angles and is called "high angle" porpoising. These curves are called the lower and upper limits of stability, below or above which instability occurs.

Low angle instability is solely due to hull forebody design except in the hump region. Tests of a forebody alone show that the lower limit occurs at very high trims at low speeds, the trim decreasing as speed increases. Thus the effect of the afterbody is to damp the motions in the hump region and cause the limit to occur at lower trims. It has also been found that if the afterbody is removed the upper limit is raised by 3° or 4°. Increasing forebody deadrise also raises the limit.

High angle instability occurs at trims and speeds which nearly mark the configurations at which the afterbody enters the water; thus

it is dependent on the geometry of the afterbody and, in particular, the afterbody keel angle. If the upper limit is crossed at midplaning speeds the attitude is so high that the aircraft is usually thrown clear of the water and stalls on again, perhaps in a regular pattern. When the aircraft is thrown entirely clear of the water intermittently the motion is distinguished by calling it "skipping." This may occur on both take-off and landing, but is more often met with in landing. The skipping characteristics of an aircraft depend to a great extent on the geometry of the step and step fairing.

Because of American tank-testing technique, a second type of upper limit instability is experienced. The model is trimmed up until porpoising occurs and the angle noted. The trim is then decreased until porpoising ceases. The angle this time is lower than before because water clings to the afterbody after contact and does not break away until the latter has been pulled appreciably clear of the undisturbed trough. The two limits are called upper limit increasing and decreasing trim respectively (*see* Fig. 12).

If a craft meets a disturbance in the hump region between the upper and lower limits, instability may occur, due to inadequate tail damping at these speeds. A second type of interlimit instability, known as "interference instability" is experienced with some aircraft at high speeds. This is because the afterbody design does not allow free entry of air between the bottom and the trough. High suctions then occur, because the limited air supply is entrained and drawn away in the water faster than it can be replaced, so that

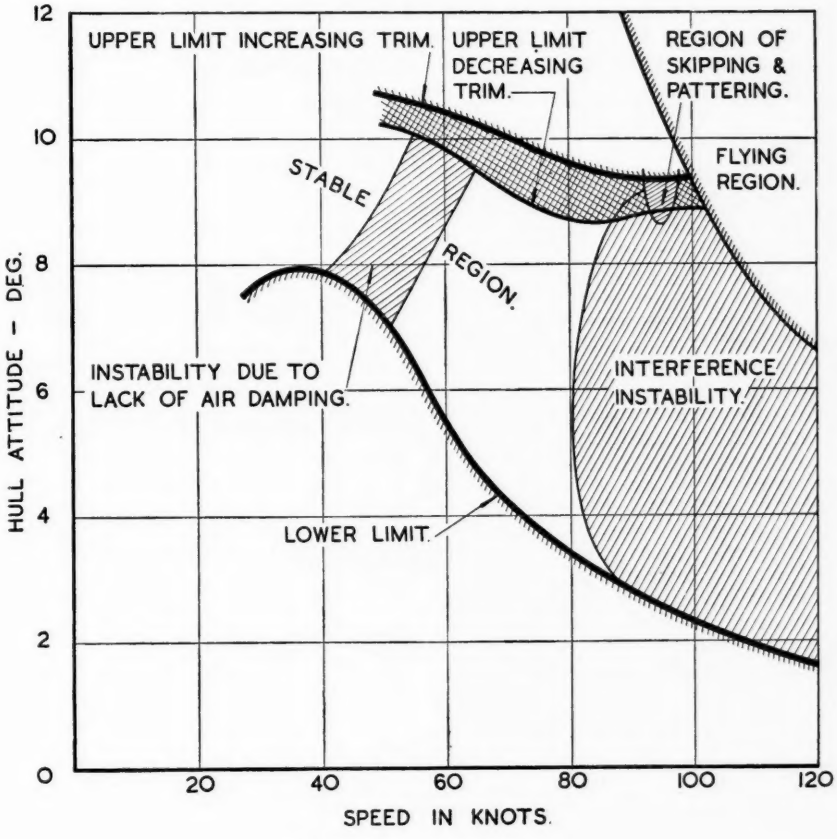

Fig. 12. Water stability diagram.

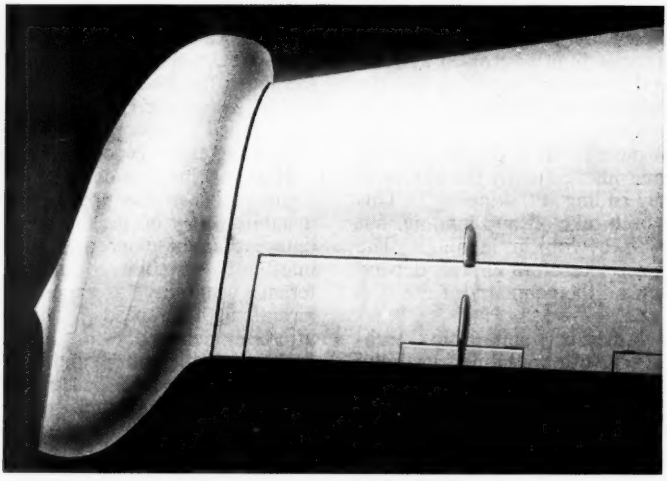

Fig. 13. Wing tip float.

the water intermittently sticks to the hull bottom.

Other types of instability that can occur include a small amplitude "skip" just before take-off, due to spray from the forebody striking the afterbody. In the same region is encountered "pattering," in which the afterbody appears to remain just touching the water while the main step comes clear intermittently. Interlimit porpoising is not of great importance because aircraft normally accelerate through these regions before the motions have time to develop.

With the advent of hulls of high length/beam ratio, deterioration of stability with increased fineness has been noticed. With hulls of conventional length/beam ratio of about 6 it was found that increases in load raised the lower limit and it was necessary to limit the forward range of c.g. in order to take off. With the large increases in loading made available by using high length/beam ratios this trend has been accentuated. In subequent investigations to overcome this difficulty, it was found that for good planing stability the forebody bottom must have no longitudinal curvature over the area wetted at planing speeds, this region being from the main step to about one and a half beams forward of the step.

During systematic investigations of the effects of high length/beam ratio it was found that constant deadrise angle over the aforementioned region caused the forebody to become much more powerful than the afterbody, resulting in higher static trims. To counteract this, lines were developed which decreased the forebody power. This was done by increasing the deadrise in a uniform manner, while still maintaining straight buttock lines. It was then found that increasing the forebody warp improved the lower limit, forebody warp being defined as the increase in deadrise angle per beam. This warping need only extend one and a half beams forward of the step; beyond this point the buttock lines may be curved in order to give the required angles of deadrise at the bow.

The investigations included the effect of increasing afterbody angle; thus it was found that this raised the upper limit, the optimum angle being about 9°, depending on detailed design.

The present complete knowledge of what was in the past an obscure phenomenon makes it possible to eliminate, by systematic tank-testing, the various forms of instability which may occur.

Lateral stability

Flying boat hulls are laterally unstable because their metacentre is below the c.g. Two methods of securing lateral stability are in common use, sponsons and lateral floats.

A large number of successful flying boats have been fitted with stub wings (or sponsons) but the view in the United Kingdom is that, although there are a number of advantages which can be claimed for them, the loss of efficiency due to extra drag and weight is too great a price to pay. Therefore, it is not expected that sponsons will have many advocates in the future.

Lateral floats can be of two types—those which are retracted into the wing tip and those positioned inboard. The inboard type have the advantage of being attached to a stronger part of the wing structure but retraction is difficult, particularly as they are necessarily larger, because of their small moment arm. Nevertheless, retracting systems have been devised which permit the complete retraction of the float and chassis into the wing.

Another solution is to retract the lateral floats into the outer engine nacelles. An example of this is the system used on the Latécoère 631. The float was retracted by a mechanism similar to that of a landplane, to a position behind the outer engine nacelle, so that in its retracted position it formed a continuation of the streamline. The retraction had a Messier pneumatic actuator, thus giving the chassis a degree of elasticity which was found to be very effective in choppy seas.

These retraction systems are costly in weight and when structural reinforcement in the neighbourhood of the wing recesses is also taken into account it may be found that the total increase in structural weight is greater than the fuel weight saving made possible by the resulting drag reduction.

This argument does not apply in the same measure to floats which are retracted to the wing tips. These floats are smaller and the wing structure is not as seriously weakened by recesses to take the chassis. With floats retracted to the wing tip the effective aspect ratio of the wing is increased and there is a beneficial effect from the floats, acting as end plates. The improvement in induced drag in cruising flight goes some way to compensate for the increase in profile drag. A modern example is shown in Fig. 13 where the float has been made to blend into the wing tip.

Assessment of the restoring moment necessary for lateral stability on the water depends on the flying boat's operational use. The upsetting moments can be listed as follows:—Static moment due to negative metacentre height; lateral wind moment, found from wind tunnel tests, or estimated from generalised data; propeller torque reaction; static moment increase, due to inclination of the aircraft when riding on waves; inertia moment due to rolling motion; inertia moment due to turning during taxying.

A combination of these moments may produce forces tending to bury the floats during low speed taxi runs, and it is found that careful design is necessary to ensure that the lift of the float is progressive with increasing speed. This can only be obtained by float development in the towing tank. It is possible to use a step form which is favourable to low drag increase since its fore-and-aft stability is unimportant.

The float supporting structure must withstand landing impact in circumstances of dropping wing and adverse cross wind, in addition to the usual taxying conditions. This calls for a high degree of sturdiness. Modern technique in assessing these impact forces, to be referred to later, will ensure that float chassis are adequate to meet emergency conditions.

It has been found from experience that some elasticity in the float supporting structure is an advantage; thus a cantilever structure is suitable, a circumstance of some convenience when designing float retraction.

Directional stability

In the past, with lightly-loaded hulls and engines offset widely on the wings, ground looping has not been a problem (although the tendency to directional instability has always been present) as it has been possible for the pilot to check incipient yaw by application of asymmetric power. Recently, due to change configurations and heavy loadings, the problem has become important. Instability is usually worst at, or just before, the hump speed during take off, but it can also occur during the landing run.

The modern research instrument is the free-launching tank, in which dynamic models are catapulted into free gliding flight, from which they are landed under varying conditions of attitude and rate of sink.

Experimental evidence covering a wide variety of past and present designs, indicates that most hulls are basically unstable. This type of directional instability is caused by water flowing up around the afterbody sides and tail cone. It is aggravated by the sides overhanging the chines of the last third of the afterbody. By employing high length/beam

ratios in present day hull design the tail extension behind the second step can be eliminated and thus overhanging afterbody is avoided. Associated with this improvement is the disadvantage of the greater controlling moment necessary with long hulls.

There are three methods of preventing or overcoming directional instability. These are by the use of

(*i*) *Skeg.* This is simply an additional keel plate below the afterbody extending forward of the second step. If of sufficient size this is effective in curing directional instability. Its success is limited to the range of trims at which it will run in solid water.

(*ii*) *Water rudder.* With jet-engined flying boats a water rudder is essential, as the possible offset thrust moment is small. With large aircraft it may be necessary to provide power assistance for its control.

(*iii*) *Water flaps.* This is a new device consisting of the equivalent of a split water rudder. The flaps are mechanically operated and combine the functions of water brakes and water rudder. These flaps supply powerful controlling forces, and it is claimed that, even in the most severe conditions, yawing can be counteracted and a directionally stable take off can be made.

2.2.5. *Waves*

The sea conditions in which a flying boat is required to operate depend on its type and duty. The majority operate from harbours, roadstead or estuaries where the depth of water is such that waves of greater size than 3 ft. from trough to crest are unlikely. On the other hand, a flying boat should be capable of alighting on the open sea and, for some special duties, both alighting and take off, may be necessary. The size and form of the waves which are likely to be encountered is important.

In any particular area waves, due to local wind condition, are probably superimposed on one or more swells originating from different generating areas. The sea in which the flying boat is to alight, therefore, is most probably irregular, having a major swell direction interfered with by a lesser swell from another direction, on which is superimposed waves running in the direction of the local wind. It is for this reason that wave conditions in the open sea have such a tumbled appearance.

The length/height ratio of waves varies from over 100 down to 7. Waves of less ratio than this are unstable and break. Long swells exceeding, say, 750 ft. and of moderate height are not dangerous provided that the wind component along the swell is less than 20 knots, for then the flying boat can run parallel to the wave crests. If the wind exceeds 20 knots, operation into wind is probably essential because of directional stability, drift and reserve buoyancy considerations. In contrast, severe impact loads and bouncing can occur in relatively short steep seas. A long shallow swell can also produce high accelerations if the craft is thrown off the crest. The most critical wave length for any particular hull appears to be between two and three times the hull length.

Pilots are advised to observe the sea from an altitude of about 2,000 ft. in order to find a region of relative calm where the interference between the various wave systems is tending to cancel rather than to build up by superimposition. If the sea has a predominant heavy swell in a given direction, then it may be preferable to alight along the swell even when the local wind is on the beam.

The technique of alighting in rough water is now better understood, and this opens up the possibility of flying boat use for duties which have not been considered possible in the past. For example, with a suitable hull design it has been found possible to alight safely in seas up to 9 ft. from trough to crest.

2.2.6 *Water loads*

A considerable amount of research information on accelerations and local impact pressures has been accumulated over many years, but recently the application of strain-gauging and the recording oscillograph has made it possible to measure transient stresses and accelerations with accuracy.

Full-scale impact acceleration measurements have been made using the latest form of instrumentation, both in calm and rough water, to check the magnitude of peak accelerations, and this has supplied data for comparison with theory.

In the United Kingdom, as a result of joint investigation made by the Royal Aircraft Establishment, the Marine Aircraft Experimental Establishment and the Saunders-Roe Company, theoretical estimates of peak accelerations have been made which give values agreeing well with full-scale results. It is difficult to make accurate measurements of the instantaneous pressure

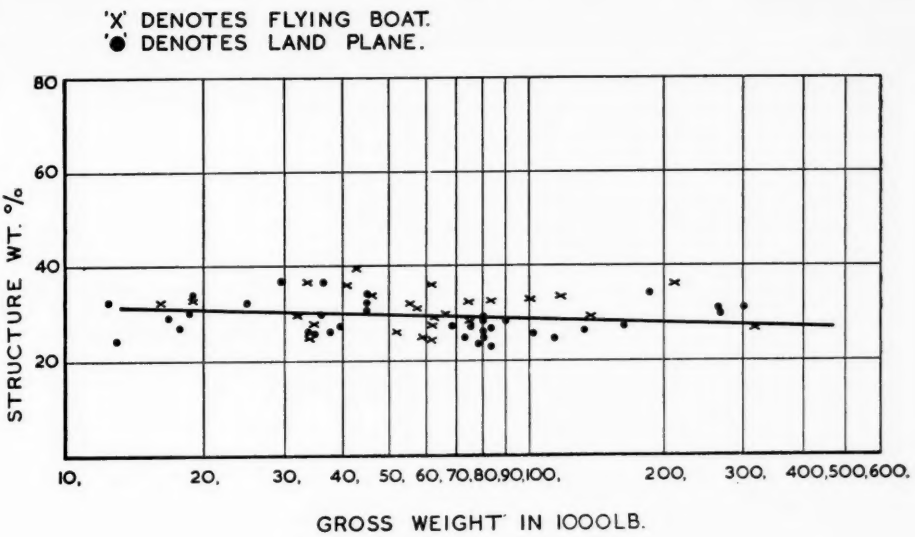

Fig. 14. Structure weight percentage.

distribution over the skin of a body in motion in a fluid surface, and mathematical computation is only possible in simple cases such as the two-dimensional. However, such calculations, based on recent theory, give shapes of pressure distribution which are very similar to those measured in practice. It will be appreciated that no mathematical computation of the distributed pressures can be acceptable unless this gives results which can be satisfactorily related to the structural strength of flying boat hulls which have withstood operational conditions satisfactorily.

Therefore, a method of approach is to choose suitable mathematically obtained pressure variations, both transverse and longitudinal, and to correct them by scale factors and subsequently to combine them to give three-dimensional pressure variations appropriate to practical cases. A convenient scale criterion, which can be measured experimentally, is maximum pressure. By using a generalised formula for the peak pressure, based on theoretical and experimental evidence, the combination of reasonable two-dimensional variations may be used to predict a fairly accurate three-dimensional pressure distribution. A number of peak pressure formulae have been developed in the past which have agreed with experimental results, but these have contained empirical factors and have not been found satisfactory for general application. The recent work which has been done by the Saunders-Roe Company's Hydrodynamic Department in developing a physically sensible expression, which yet gives good agreement with experiment, has made it possible to approach, with confidence, an assessment of the impact loads necessary for the structural design of future flying boats.

Reference to one or two of the test results which have been used in the correlation of theory with full-scale may be of interest. Calm water landings of a Sunderland V, which recorded impact accelerations of 1.0 to 1.3 *g* gave mean pressures between 12 and 15 lb./in.², with peak pressures of about 25 lb./in.² recorded locally. These pressures are of very short duration being of the order of $\frac{1}{10}$th of a second. Similar tests on a Sikorsky S.43, showing a similar acceleration (1.3 *g*), recorded average bottom pressures of about 9 to 10 lb./in.², with peak pressures which vary from 15 lb./in.² at the keel to 18 lb./in.² at the chine. These values are representative of normal landing cases, but with landings made into rough seas, and particularly with heavy swell, much higher accelerations have been recorded. In some notable tests recently made on a Mariner and Mars, where landings were made into exceptionally heavy seas, accelerations as high as

5 *g* were measured. At the same time, rotational angular accelerations were recorded, sufficient to produce accompanying accelerations at the bow or tail of 9 *g* and, in one exceptional case, 11 *g*.

These figures are for abnormal conditions obtained during investigations into the maximum values which can be encountered, but it is noteworthy that the structures of these two aircraft were capable of withstanding these loads. It is unusual, in normal practice, for accelerations to be developed which exceed 2.5 *g* at the c.g.

2.2.7. *Weight*

A few years ago it was generally assumed that flying boats were heavier, structurally, than the corresponding landplane, but flying boat defenders have rejected this assumption with vigour and it is now universally admitted that flying boats have no greater structure weight than landplanes and, in the larger sizes, there is even a tendency in favour of the boat. As this subject has already been dealt with adequately in a number of technical reports and papers, this ground will not be covered again, but, in view of the importance of weight when very large aircraft are considered, the effect of increased size on structure weight will be discussed.

Statistics of structure weight percentages covering the past ten years are shown in Fig. 14. The structure weight percentage plotted against all-up weight indicates that the upward trend, predicted from consideration of the so-called square/cube law, has not so far become manifest; in fact, the largest aircraft quoted, in the 300,000 lb. range, show a lower percentage than the average medium-sized aircraft. This unusual result has been achieved by the action of certain beneficial factors which have alleviated the adverse effect of the scale law.

It is thought that one of the reasons for this result has been the parallel growth in size of aircraft with increase in knowledge and attention to detail design. Other factors which have helped are:—

(*i*) The wing loading has increased with size —this can be shown to be a statistical fact, for which there are a number of reasons, probably the most important being the availability of longer runways for the larger aircraft. The maximum limit in wing loading has not yet been reached, and as the water runways for flying boats are not restricted in the same way as with landplanes it is evident that this assistance to weight alleviation will continue for further size increases.

(*ii*) When materials of higher specific strength have become available it has been found advantageous to apply them in large aircraft, where it pays to design each part exactly to suit the load, whereas the size of many parts on small aircraft is decided by the necessity for handling or general sturdiness. It is evident that the development of new materials of increased specific strength has by no means reached finality, recent innovations being zirconium alloys and, still more recently, titanium.

(*iii*) Lower strength factors have been found to be permissible with large aircraft since, owing to the slower acceptable rate of control response, the accelerations to be met in flight are less. This argument is supported by the present international requirements for strength factors which permit lower factors for large aircraft. This weight alleviation has operated in the past but will not help the future aircraft of increased size; on the contrary, recent gust requirements show a tendency to increase, and new thoughts on the accumulative effect of repeat loading on fatigue properties may result in increases in structural weight.

(*iv*) By more careful consideration being given to the disposition of the main structural members on large aircraft, it has been found possible to use material more economically and this has led to the early use of advanced technique. An example is the early application of stressed skin construction to large aircraft. Stressed skin wings are now universally used even in fighters, but it is suggested that there is still something to gain by the more economic disposition of the material in the structure. For example, with forethought in the initial design stages, holes and recesses in the wing might be avoided and a continuous unbroken wing beam might be retained through its length. Wing joints can also be omitted on very large aircraft; there is a precedent for this in certain American types.

(*v*) There are a number of items included in the structure weight which are

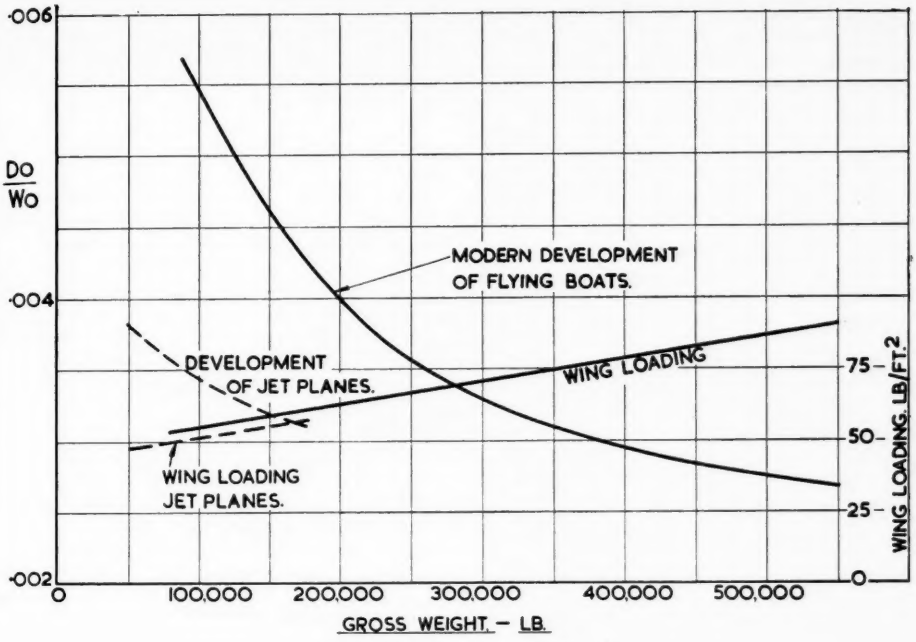

Fig. 15. Size effect on drag.

common to all sizes of aircraft, an instance being those parts which are controlled by the physical strength of the pilot, but it will be apparent that this argument applies to many other items contributing to the weight of the aircraft.

To summarise the subject of structural weight, there is so far no evidence to indicate when increase in size of aircraft, particularly a flying boat, will be accompanied by an increase in the structural weight percentage.

Arguments have been advanced recently claiming that adverse scale laws apply to the specific power/weight of turbine engines. This may be theoretically correct but it is thought that technicians are following the same erroneous conclusions which have so effectively been refuted in connection with structure weight. This statement, it must be admitted, is based on a statistical examination of the subject, but the conclusion is clear that, taking into account the technical improvements which are continually being made, the specific weight of all types of engine show improvement with increase in power. This is an important consideration in connection with the future of large aircraft.

2.2.8. *Effect of size on drag*

In the previous sections it has been shown that a growth in size does not entail a greater structure weight percentage, but this fact alone does not justify large aircraft; the real justification arises from the gain in aerodynamic efficiency which results from increasing the size.

Figure 15 shows the ratio of profile drag to all-up weight plotted against the weight of modern designs of flying boats. It will be seen that there is progressive improvement as the size increases.

This can be ascribed to:—

(*i*) The trend towards higher loading as size increases.

(*ii*) A proportionately smaller body surface area is required to contain the payload since this area varies as the two-thirds power of the volume (volume being proportional to payload).

(*iii*) Parasitic and interference drag can be more easily controlled.

(*iv*) The frontal area of the power plant does not increase proportionately with power

(in the larger aircraft the power plant can be buried).

The curve of Fig. 15 shows the effect of these factors when size is increased without allowance being made for advances in aerodynamic technique which are continually taking place. If a similar curve is constructed from analysis of actual aircraft designed during the past ten years, it is found that invariably the largest aircraft are the most recent, and the curve of reducing drag/weight ratio is found to be steeper than is shown in the diagram, due to the inclusion of this additional factor of aerodynamic advance.

It will be seen, therefore, that there is much to gain by increasing the size of aircraft, for not only is this of some benefit to the aircraft weight, but a substantial increase can be expected in transport efficiency due to the beneficial effect of increased size on aerodynamic drag.

2.2.9. *Maintenance and docking*

This lecture is on the future of flying boats, but it is now becoming evident that the problem of base handling is vital to their future; their efficient employment depends on its solution. The tradition that they should lie at moorings for refuelling, inter-flight maintenance and loading, dies hard; in fact, some operators still use this old-fashioned method. This is only possible provided that the boats are slipped frequently, so that maintenance can be carried out, the usual method being to attach a beaching chassis and haul them up a sloping slipway. This has proved an expensive method of handling, because the aircraft's utilisation is reduced by the long periods of haul-out and, when afloat, the operations are uneconomical due to the remoteness of the working parties from essential facilities. Furthermore, numerous launches and crews must be maintained.

The various airlines operating flying boats have gradually evolved satisfactory methods of handling, and there are now a number of excellent passenger docks, Southampton being a good example. Military operators, however, have lagged behind in the adoption of facilities and, in general, still use the old methods.

Flying boats should remain in the water for as long as possible before slipping or docking, and all short period maintenance work should be done afloat (Fig. 16). The floating pontoon dock appears to be the best solution to this problem, and it is preferable that this should be U-shaped so that there is access to both sides of the boat. If the dock is connected to the shore it is relatively simple to run refuelling and electrical supply lines to points on the dock. All loading and unloading can be done at the dock and facilities can be provided for maintenance access and engine changing.

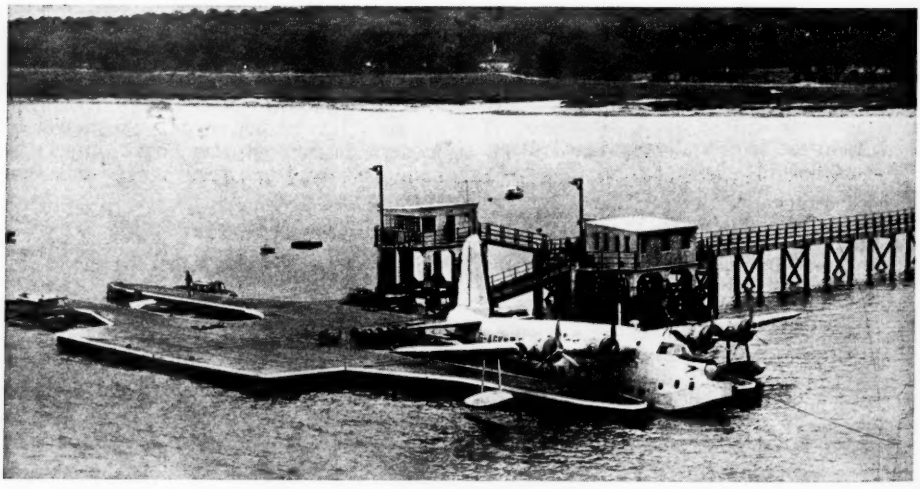

Fig. 16. Flying boat dock.

Consideration has been given, both in the United Kingdom and in America, to making pontoon docks transportable, and experimental docks have been constructed which have proved successful. Shortly it will be possible to fly out docking and other facilities to any locality chosen as a temporary base of operations.

For major overhaul it is desirable to haul out of the water, and this is also necessary occasionally for cleaning off marine growth. The more a boat is used the less frequent is it necessary to scrub.

The use of a beaching chassis so that the boat can be hauled up a slipway is the usual method and perhaps the most convenient—it is to be used with the 330,000 lb. Princess flying boat—but other ways have been tried with success, including the use of a floating dry dock. If local rock or coral is available the construction of a slipway, by tipping the rock to the required slope, has proved to be a cheap and rapid building method.

The author's views on the types of base and facilities which should be used may be of interest.

(*i*) *Maintenance base.* All major overhaul work should be done at this base. Therefore, it will have a slipway, hard standing, hangars and stores. It will also have a number of permanent pontoon docks with all necessary supplies piped from the shore.

(*ii*) *Operating bases.* All regular operating or refuelling points will be provided with a number of portable pontoon docks, with causeways to the shore carrying piped supply lines for refuelling, electrical supplies and so on. No slipways will be required as the aircraft will be flown to the maintenance base for hauling out. They will, however, carry emergency equipment for engine changing.

(*iii*) *Temporary refuelling bases.* These would be similar to the operating bases but would be equipped with a single portable pontoon dock. The dock would be used with either a floating causeway to the shore, where this is possible, with land-based refuelling storage and equipment, or from a barge moored nearby.

(*iv*) *Emergency bases.* These bases will be used infrequently and need not be equipped with more than fuel storage and means of supply. The aircraft would lie to a mooring buoy and be tendered by a local launch. Fuel would be pumped from a small lighter.

3. THE FUTURE

If the implications of the foregoing technical sections have been appreciated, it will be apparent that hydrodynamic and technological development has made great strides in the past few years but, unfortunately, this knowledge has outstripped design application.

The old facility for independent operation, which was found so useful in the past, appears to have been lost in recent years. It seems that all flying boats, both military and civil, have become "base-bound" and their unique capability of operation at improvised stations with the simplest of facilities, has been forgotten. They are tied to elaborate ground organisation even more than a landplane. For example, the main purpose of a patrol flying boat is to locate and destroy enemy submarines. It must, therefore, be capable of reaching the most distant areas likely to be infested by them. In assessing the required radius of action and the duration of local search, the answer will depend on the situation of the base. If then the base required must include concrete slipways, flight sheds and all the other impedimenta of the present conception of a marine station, the range required of the aircraft might be very different from the case where an improvised base can be used.

To take full advantage of the flying boat's unique facility for operation away from prepared bases, special consideration must be given in future designs to ensure that the minimum of outside assistance is necessary for refuelling, re-arming and inter-flight maintenance.

Some emphasis has already been placed on the increased seaworthiness which can be expected from new designs of flying boat. Capability of landing on the open sea has been an attribute of many successful designs, and it is quite usual for them to be landed at sea in emergency or for rescue purposes. By special design this feature can be improved upon so that regular landing in the open sea can be included in the aircraft's military duties. Needless to say, this will also facilitate take-off and landing in open roadsteads, thus extending considerably the localities in which the aircraft can be

operated. The improvement in hull drag now made possible has already been described, and some of these principles are already incorporated in new designs—such as the Princess—with resulting improvement in performance.

Long-range performance is of the greatest importance to nearly all classes of flying boat, particularly as flight over the sea frequently requires long distances to be flown without the option of refuelling stops. Capability of long range is one of the flying boat's most valuable assets and increased range can be regarded as attainable on future classes of aircraft, including ocean patrol boats and trans-ocean transports, both civil and military. These long-range types of aircraft will almost certainly use propellers, and there are now available three types of power plant which are suited to different classes of flying boat.

The advantage in the use of jet engines is obvious but in the class of boats in which range is of importance it is probable that propeller engines will hold their own for a long time to come. The choice here lies between propeller-turbines, piston engines and compound engines.

The propeller-turbine is suitable for the transport aircraft where high-speed operation at high altitudes is permissible. This type of engine, however, lacks flexibility in operation and a strict flight plan must be followed, involving the use of maximum cruising power at the maximum altitude throughout the flight.

The piston engine, as such, is on the way out for long-range aircraft, although it still has a future for short-range types, such as feeder-line aircraft or amphibians. Already the airlines are going over to the use of compound engines and it is clear that this type of plant is to take an important part in future development. The newest development in the compound engine, and one particularly suitable for certain classes of flying boats, is exemplified in the Napier "Nomad." This engine is new in principle and consists of a compression ignition diesel, the exhaust from which drives a turbine coupled to an axial compressor, which in turn supercharges the diesel. In addition, the surplus power from the turbine supplements the main shaft output. This type of engine is capable of exceptionally low specific consumption, and its flexibility makes it particularly suitable for ocean patrol flying boats which are required to operate over a wide range of altitude and speed.

It has been seen in earlier discussion on the weight aspect, that the size of future flying boats is virtually unlimited. Therefore, for aircraft which require to have great capacity the flying boat is perhaps the only type worth considering, since growth in size with landplanes is limited by the availability of runways, and this limit must have been reached already.

The future availability of flying boats with low drag, besides offering greater range and economy, also opens up the possibility of their use for duties which in the past have been considered the prerogative of landplanes. The operation of intruder bomber squadrons from remote quarters of the world is now being considered. By the use of improvised bases, the radius of action necessary can be reduced to distances which permit the design to be primarily for speed and, with present knowledge, this may be contemplated as being in the transonic region.

As a result of the research which has been done by Saunders-Roe in England, and Convairs in the United States, the water-based fighter has been brought into the field of military strategy. This type of fighter is capable of operation both from distant locations and also for home defence, where the indestructability of the runways is a feature which must be taken into consideration in future defensive planning. The speed of this type of aircraft is not limited in any way by its water characteristics, and machines in the supersonic class can be considered.

Consideration will now be given to each particular type of water-based aircraft.

3.1. Ocean Patrol Flying Boat

The operational requirements of ocean patrol flying boats have already been outlined. Looking to the future it is not thought that fundamental changes will be necessary in their method of operation, but a greater radius of action is foreseen.

No doubt new methods of detection will be developed in the near future in addition to radar and sono-buoy location. For example, it has been suggested that the patrol boats should alight at sea, lying to a sea anchor, while sub-surface methods of detection are employed. This brings into prominence the

high seaworthiness which can be provided in future flying boats of this type.

The necessary radius of action and endurance in the search area will decide the size of boat to be used, but it is a matter of economics that the smallest aircraft which can carry out a given duty is the one which is most suitable. This is particularly so with a patrol aircraft of the type under consideration since it is obviously better to have two small aircraft for search purposes than one large one.

As an indication of the general trend, Fig. 17 shows a design for an ocean patrol boat of the immediate future. The size is in the region of 150,000 lb. and it has four compounded diesels driving propellers. The boat will be capable of cruising at 400 m.p.h. for a gross range of 8,000 miles or, alternatively, the patrol speed can be reduced to the neighbourhood of 200 m.p.h., and a gross endurance of 35 hours can be obtained. This boat has a high aspect ratio wing, with a loading of 65 lb./ft.^{2}, and the hull has been designed with a fineness ratio of about 12.

3.2. Intruder Bomber Flying Boat

Because of the high speed necessary with modern attack bombers the radius of action is limited, and unless an aerodrome is available within striking distance of the target the mission must be delegated to carrier-based aircraft. A water-based bomber, however, could use a base improvised almost overnight, within suitable range of the objective. This form of bomber can also be used for mine laying.

The problem of carrying bombs on a flying boat has been solved in a number of existing aircraft, and new methods have been projected so that the flying boat need not suffer from any disability in this respect.

In looking to the future employment of flying boats, their use in the role of bombers should receive careful consideration. The study shown in Fig. 18 shows a version of this type of flying boat. It is the logical development of an aircraft such as the Saunders-Roe SR/A1, and, when fitted with the engines contemplated, it will be capable of flight in the transonic region.

3.3. Military Transport

The Princess flying boat has already been described. This aircraft was designed primarily for the carriage of passengers over long-stage distances, but it is surprising how adaptable this class of aircraft is for troop-carrying. It holds this advantage in common with civil landplane types but, being a flying boat, it can fly to areas in which aerodromes are not available or are non-existent. Flying boats have already been used in this way on

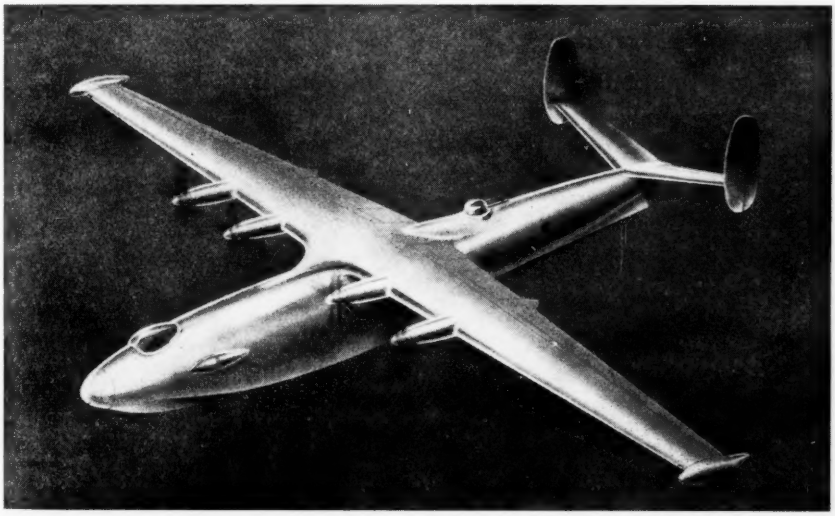

Fig. 17. Design for an ocean patrol boat.

numerous occasions. A flying boat is, at times, the only type of aircraft which can be used for evacuating civilians from danger areas.

The transport of troops by air will become universal in the future, not only because of the advantage in rapid reinforcement but in order to eliminate the loss of effectiveness while the troops are on journeys of long duration by sea.

For troop-carrying duties there does not appear to be a case for a special military design, and it can be assumed that adapted civil aircraft will continue to be used for this purpose. This procedure also has the advantage that the aircraft used will be a well-tried type.

The last argument, however, cannot be used with regard to flying boats required to carry military material. The items to be carried are very diverse and may have excessive dimensions in one or more directions. Experience has shown that aircraft designed for passenger-carrying are incapable of accommodating the equipment and supplies which must be available to the airborne troops.

The transport flying boat appears to be the obvious answer to this problem, since it is virtually unrestricted in size and does not require prepared aerodromes. Placing the main doors in the bows simplifies loading and makes it possible to use the flying boat as an assault craft, which can be run, bow first, on to a suitable beach.

Flying boats of 330,000 lb. total weight are soon to fly in Great Britain, and in America a boat of 450,000 lb. has been built. The former, the Princess, has a lower structure weight than contemporary boats of similar size; hence, an increase in dimensions can be contemplated, if this is found to be necessary, in order to carry specialised military equipment. The limiting factor in size in the future will probably be the availability of engine power. There is also the difficulty in efficiently converting high shaft power into thrust. For this reason the author would set a limit to the upward rise in weight for some time to come to about 600,000 lb.

3.4. Commercial Flying Boats

Before discussing the use of flying boats in future air travel, it will be useful to consider what qualities the passenger will expect in order to attract him to a particular airline. These qualities are not difficult to define and are given in order of precedence. (*a*) A smooth ride, (*b*) short duration journey, (*c*) quietness, (*d*) creature comfort.

The smooth ride can be achieved provided that the aircraft flies above turbulent cloud layers. This means operating at heights above 20,000 to 25,000 ft. Increase in size, in wing loading, and in aspect ratio, have also a controlling influence in reducing aircraft movement in disturbed air. Short duration of flight—*i.e.* reduction in elapsed time rather than high cruising speed—is obviously the criterion of performance affecting the

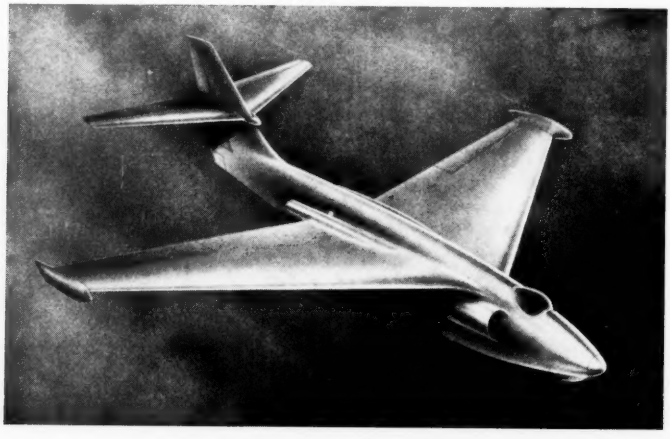

Fig. 18. Design for an intruder-bomber flying boat.

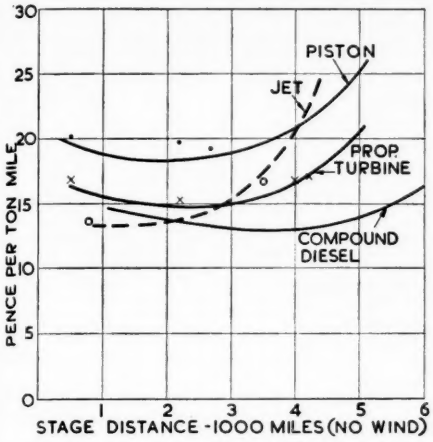

Fig. 19. Operating costs for different engines.

passenger. This really calls for both a high cruising speed and long range, two attributes difficult to attain simultaneously. Without sufficient range refuelling stops must be made, which have a disastrous effect on the average speed on the overall journey, and it is possible for a much slower aircraft, but one having sufficient range to avoid refuelling, to show a higher average speed on the overall journey than a really high-speed type. Consequently, it is probable that in a few years time the regular trans-Atlantic crossing will be made direct, in both directions.

Quietness is an important quality from the passenger point of view, and its importance needs little justification. It is perhaps easier to obtain a quiet aircraft with propeller-turbine power plants than with other types of power and, by the use of a large aircraft, the distances between sources of noise and the cabin walls can be increased with beneficial results.

Creature comfort includes all the amenities which further attract the passenger, and no doubt it will generally be agreed that the amount of comfort provided should increase with the duration of the trip. The fact that large aircraft are necessary for long-range operation has already enabled operators to increase the comfort of aircraft used on trans-continental and trans-ocean journeys. In looking to the future a steady improvement can be expected in the provision of passenger amenities, particularly on long routes.

It has been found possible to meet many of the desired qualities discussed in designing the Princess. By reason of its size and the use of propeller-turbines, which show their most economical operation at high altitude and by relatively high speed, this flying boat satisfied in most respects the qualities which have been enumerated.

The availability of jet engines has turned thought to the possibility of high-speed medium-range transport aircraft. The Comet has shown that satisfactory passenger land-planes are possible in spite of the excessive consumption of the jet in comparison with reciprocating engines. The justification for their use is their high speed, since the running costs of an aircraft are for the most part related to the time the aircraft flies, whereas revenue is proportional to the distance flown.

The results of a recent investigation are reproduced in Fig. 19. These curves have been constructed for a series of similar aircraft which are designed to give optimum transport efficiency over varying distances, their size being adjusted accordingly; they show estimates for the cost of operation per ton mile for varying stage distances. It will be seen that for medium ranges the jet aircraft can be a better economic proposition that a propeller-driven aircraft. This economic advantage can be improved materially if, by reason of the aircraft's speed, a return journey can be made in one day on a route where the lower speed aircraft can only schedule a one-way trip. It is thought that the jet-engined passenger aircraft will eventually become universal for stage distances of 1,000 to 2,000 miles.

A brief comment on the curves for propeller engines may be of interest. In this assessment the piston engine suffers from the use of more costly high octane petrol, has higher drag and uses low cruise power; hence it has lower speed.

The propeller-turbine is superior in all these respects, using a cheaper fuel and having high cruise power for low drag.

Finally, the compound engine has the big advantage of low consumption of a cheaper fuel. It has, however, low cruise power and medium drag, and offers only low cruise speed. Hence, the effect of headwind, for which no allowance has been made, will be important.

Figure 20 shows a flying-boat project which meets well the foregoing arguments for a jet-engined machine. It represents the passenger flying boat of the immediate future, and has been designed to operate on stage

distances of about 1,500 miles at a cruising speed of 450 m.p.h. The maximum take-off weight is 130,000 lb. and the aircraft is fitted with six de Havilland Ghost engines. This engine fits well the specified requirements and although other jet engines are available with lower specific consumption they have greater power, and the size of the aircraft, in order to obtain similar operating costs, would have to be increased. Furthermore, the larger aircraft would show its best economy over a greater stage distance than that actually required by the specification.

Looking further into the future of this class of flying boat, there does not appear to be a great gain in operating a passenger aircraft with a higher cruising speed than 500 m.p.h., and it is probable that future development will be in range and size so as to fit it more for trans-ocean journeys at present being operated by relatively slow aircraft requiring refuelling stops.

3.5. Water-based fighters

Reference has already been made to the first attempt in modern times to produce a water-based fighter, when describing the Saunders-Roe SR/A1 and the future capabilities of this type of aircraft, in its role as an interceptor, were discussed. Study of the SR/A1 suggests that in a later generation of fighters a radical change in outlook is necessary if the performance is to compete on equal terms with a land-based fighter, and the conclusion is reached that no concession can be made during flight to hydrodynamic requirements.

It is clear that the conventional flying-boat hull, even with the most modern refinements, must be discarded and other means found to provide satisfactory water behaviour. Fortunately, the jet engine power necessary for high performance in flight makes it possible to adopt low efficiency hydrodynamic systems for water operation, and to concentrate on a blending of the characteristics which contribute to both high-speed flight and satisfactory water behaviour.

Operation from the water introduces a number of new problems which require solution. For example, the jet engine intake must be in a position free from spray and yet have satisfactory ram efficiency, and access to armament and equipment must have special consideration.

Fig. 20. Design for a jet civil flying boat.

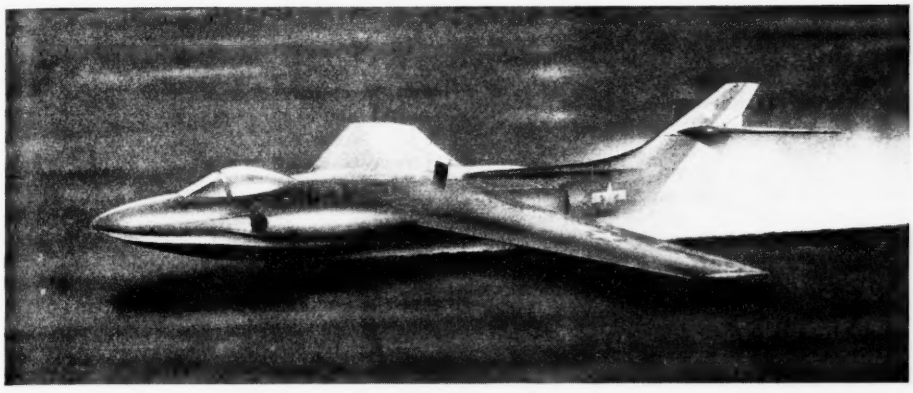

Fig. 21. Convair design for a water-based fighter.

These difficulties and many others can be overcome, and Fig. 21 shows the lines on which Convairs have found a solution for an attack fighter-bomber. The method of development used by them is by powered models controlled by radio from a ground station. By this method the three-dimensional behaviour of a model can be investigated during all phases of take off, flight and landing.

By the more usual method of development —*i.e.* by the use of towing tank, launching tank and wind tunnel—and somewhat in parallel with the Americans, Saunders-Roe have designed a high-speed water-based fighter in which hydro-skis are used. Reference was made to this earlier, when it was pointed out that a satisfactory hydro-ski system had been developed which was capable of complete retraction.

The fighter shown in Fig. 22, although capable of taking off from water, is no longer a flying boat in form and, when in flight, is on equal terms with the equivalent land-based aircraft.

In this design the jet engine has its air intake above the fuselage in a form of pitot entry, which has been developed in the wind tunnel to give high overall efficiency.

These water-based fighters illustrate the future posibilities of aircraft which are independent of runway construction and, therefore, are capable of use in any area of the world, provided that there is sheltered water from which to operate.

3.6. Atomic Powered Flying Boat

It has recently been announced in the United States that work has been initiated on an aircraft deriving its power from nuclear fission. The use of this form of energy opens up possibilities for long-range operation hitherto undreamed of, but consideration of its ultimate uses are profitless at this stage and it is proposed to confine discussion to its initial application, which might well be associated with a flying boat. The following reasons are given in support of this statement.

So far there is no clue to the nature of the reactor being developed, nor the method of converting the energy into thrust, but it is probably safe to assume that only the heat energy of nuclear reaction can be used and, further, it can be inferred that vapour-driven turbine engines with propellers will form the power units, at least in early installations.

The weight of reactor unit, controls and screening will be high. This part of the installation takes the place of the fuel load in the conventional aircraft. A very approximate approach to the aircraft weight indicates that for structure, engines, take-off assistance and useful load, roughly 60 per cent. of the total weight will be required. Therefore, for a reactor unit weighing, say, 100 tons an aircraft of from 500,000 lb. to 600,000 lb. weight will be necessary. This is a very big aircraft to contemplate as a landplane but as a flying boat such a size would be acceptable without query.

The atomic-powered aircraft will cruise at constant weight and power throughout the flight and it can be assumed that, for economic reasons, the cruising power will approach the maximum of which the plant is capable. As a consequence, for take-off and initial climb, assistance from some other form of energy, such as liquid rockets, will be necessary. In order to reduce power assistance as much as possible it will be wise to make the take-off from water, where runway length is unrestricted.

Since the weight of fuel consumed is insignificant, the design optimum aerodynamic conditions should prevail throughout the flight, and the unusual condition is met in which the take-off and landing weight is the same. The possibility of landing flying boats at their take-off weight has always been recognised as an acceptable manoeuvre. The unobstructed approach run, unrestricted landing area, and short run after touch-down reduce the landing hazard, and the shock-absorbing properties of a Vee bottom ensure low landing accelerations even at overload weights.

The opinion has been expressed that turbine-driven propellers will be used. This does not necessarily restrict the performance to subsonic speeds since supersonic propellers will soon be available, but it is thought that for an aircraft capable of very great distance, and in order to limit accelerations developed in disturbed atmospheric conditions, the cruising speed of the first atomic aircraft will be subsonic.

4. CONCLUSION

The last subject is an appropriate one on which to close this lecture, in which it has been the endeavour to trace the main factors contributing to the continued development of flying boats and, by an account of the considerable advances in hydrodynamic knowledge made in recent years, to predict the trend in future design.

The first half-century of flight approaches and throughout this period aviation has been developing rapidly, so much so that at any time the aircraft just newly flown, because of the gain in knowledge acquired since its inception, has become virtually obsolete, and the surprising thing is that this state of affairs holds today as much as in the years past.

NOTATION

b	beam of hull
C_Δ	load coefficient equal to $\Delta/(wb^3)$
D_0	profile drag corresponding to zero lift
g	acceleration due to gravity
K	load coefficient equal to $\Delta/(wl^2b)$
k	ratio of drag to the drag of a body of revolution
l	length of planing bottom
R	resistance
W	weight of aircraft
W_0	gross weight
w	unit weight of water
Δ	displacement of aircraft

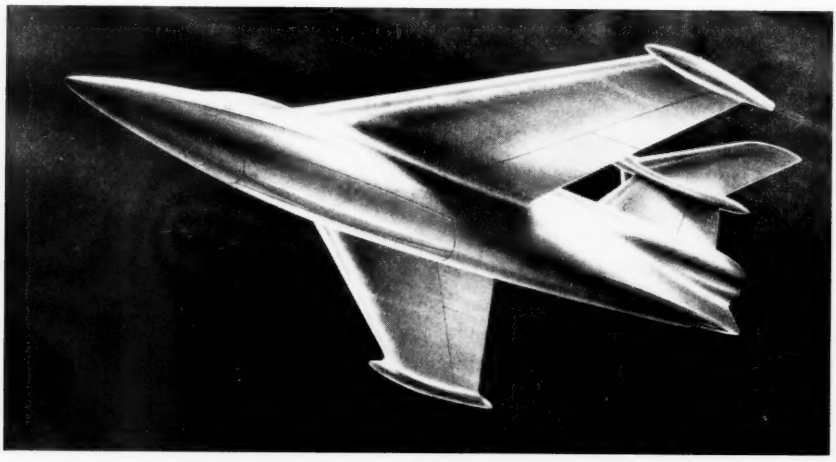

Fig. 22. Saunders-Roe design for a water-based fighter.

An innovation this year was a short discussion following the lecture, during which interesting contributions were made by Monsieur Jarry, Monsieur Hurel, Monsieur de Faget, Monsieur Lucien and Monsieur Benoit.

After the lecture a cocktail party was held and later a banquet was given by the Council of A.F.I.T.A. at the Aero-Club de France at which speeches were made by Monsieur Jarry, Air Commodore Banks, Monsieur Hereil (Président de la Chambre Syndicale des Industries Aéronautiques) and Monsieur Pierre Montel, Secrétaire d'Etat à l'air. Among those present at the dinner were the following:—

Monsieur Allais, Directeur de la Sté Commerciale et Industrielle Franco-Britannique; Monsieur L. Armandias, British Messier Ltd., and A.F.I.T.A. Representative in London.

Dr. A. M. Ballantyne, T.D., A.F.R.Ae.S., Secretary, The Royal Aeronautical Society; Air Commodore F. R. Banks, C.B., O.B.E., F.R.Ae.S., Member of Council, The Royal Aeronautical Society, and Technical Manager and Chief Engineer, Associated Ethyl Co. Ltd.; Monsieur Barret, Chef du Cabinet de M. le Ministre de l'Air; K. J. G. Bartlett, Esq., A.F.R.Ae.S., The Bristol Aeroplane Co. Ltd.; Miss F. Barwood, The Royal Aeronautical Society; Monsieur Becq, Directeur du Centre de Revision de Courbevoie; Monsieur Benoit, Conseiller à l'Office National d'Etudes et de Recherches Aé, Membre du Conseil A.F.I.T.A.; R. Blackburn, Esq., Hon.F.R.Ae.S., Blackburn and General Aircraft Ltd.; Monsieur Ed. Blanc, Rédacteur de Technique et Science Aé; E. C. Bowyer, Esq., Director, Society of British Aircraft Constructors Ltd.; Monsieur L. Breguet, Président, Directeur Général de la Sté Louis Breguet; Monsieur P. Breguet, Directeur de la Sté Louis Breguet; Monsieur L. Brocard, Membre du Conseil A.F.I.T.A., Ingénieur en Chef Sté Louis Breguet; Monsieur Buret, Ingénieur en Chef a la Société Nationale de Constructions Aéronautiques du Nord.

Monsieur Calandreau, Ingénieur Bureau de Normalisation de l'Aéronautique; Monsieur Calvy, Ingénieur en Chef à la Sté Nationale de Constructions Aéronautiques du Nord; Ingénieur Général Champsaur, Directeur du Département Etranger Entreprises Metropolitaines et Coloniales; Monsieur Chassagny, Président Directeur Général Sté MATRA; B. Sandford Clark, Esq., Rotol Ltd.; Air Vice-Marshal Sir Conrad Collier, K.C.B., C.B.E., A.F.R.Ae.S., Director, D. Napier and Sons Ltd.; H. G. Conway, Esq., F.R.Ae.S., Technical Director, British Messier Ltd.; Monsieur Coroller, Membre du Conseil, A.F.I.T.A., Directeur Technique de la Sté Nationale de Constructions Aéronautiques du Nord.

Monsieur J. Dellery, Directeur du Service Aviation Shell; Monsieur Deplante, Membre du Conseil, A.F.I.T.A., Directeur Technique Avions Marcel Dassault; Monsieur Desbrueres, Directeur Général S.N.E.C.M.A.; Monsieur Diconne, Ingénieur Sté Nationale d'Etudes et Constructions Aéronavales; Dr. G. P. Douglas, O.B.E., M.C., F.R.Ae.S., Member of Council, Royal Aeronautical Society, and Head of the Aerodynamics Department, Royal Aircraft Establishment; Monsieur Dubois, Président de la Sté Avions Hurel-Dubois; Inspecteur Général Dumanois, Membre d'Honneur de l'A.F.I.T.A.; Monsieur J. C. D. Duyster, Ingénieur en Chef Sté Fokker.

Lt.-General Sir John Evetts, C.B., C.B.E., M.C., Managing Director, Rotol Ltd.

Monsieur de Faget, Chef des Relations Extérieures de l'O.N.E.R.A.; L. G. Fairhurst, Esq., Chief Engineer, Rotol Ltd.; Group Captain G. Feltin, Royal Aircraft Establishment; Monsieur Foch, Membre du Conseil A.F.I.T.A., Ingénieur en Chef Centre d'Essais en vol.

Colonel Gentil, Conseiller Technique Cabinet du Ministre; Monsieur Gerardin, Directeur Adjoint à la Direction Technique et Industrielle du Ministère de l'Air; Monsieur Gerin, Ingénieur en Chef Sté d'Etudes et Techniques Nouvelles; Monsieur Gilles, Président d'Honneur de l'A.F.I.T.A., Directeur de la Sté pour le Perfectionnement des Matériels d'Equipements Aéronautiques; H. R. Gillman, Esq., O.B.E., A.F.R.Ae.S., Directeur Général Fédération Aéronautique Internationale; Monsieur Glasser, Président Directeur de la Sté Nationale de Constructions Aéronautiques du Sud-Ouest; Colonel Goussault, Representing Armstrong-Siddeley Ltd.

A. A. Hall, Esq., M.A., F.R.Ae.S., Member of Council, Royal Aeronautical Society, Director, Royal Aircraft Establishment; Ingénieur Général Harlaut, Directeur de l'Ecole Nationale Supérieure de l'Aéronautique; A. S. Hartshorn, Esq., F.R.Ae.S., Scientific Attaché, British Embassy, Paris; Professor F. C. Haus, A.F.R.Ae.S., Professor of Aerodynamics, University of Ghent, A.F.I.T.A. Representative in Belgium; Monsieur Hedde, Ethyl S.A.; Sir Charles Henderson, K.B.E., European Purchasing Commission; Monsieur Jacques Henrat, Ingénieur aux Ets Fouga; Monsieur Hereil, Président de la Chambre Syndicale des Industries Aéronautiques; Monsieur Heurteux, Président Directeur Général Hispano Suiza; F. T. Hinkley, Esq., Rolls-Royce Ltd.; Monsieur Hurel, Directeur des Avions Hurel-Dubois; Monsieur Hymans, Président de la Sté Air-France.

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Monsieur Malavard, Chef des Relations Scientifiques Office National d'Etudes et de Recherches Aéronautiques; Monsieur Marchal, Directeur Technique Sté Nationale Etudes et Constructions de Moteurs d'Aviation; Monsieur Mauboussin, Directeur de la Sté Fouga; Monsieur Maurice, Vice-Président du Conseil A.F.I.T.A., Ingénieur en Chef de l'Air, Directeur de la Circonscription Aérienne de Paris; Ingénieur Général Mazer, Directeur Technique Industriel au Ministere de l'Air; Monsieur Menetrier, Membre du Conseil A.F.I.T.A., Directeur Technique Sté Potez; Ingénieur Général du Merle, Directeur de l'Aéronautique Civile; Monsieur Mignot, Cabinet du Ministre, Conseiller Technique; Colonel de Rancourt de Minerand, C.B.E., D.F.C., A.F.C., French Air Attaché, London; Lt. Moloney, Office of the U.S. Air Attaché, London; Monsieur Pierre Montel, Secrétaire d'Etat à l'Air; Senor Arranz Monasterio, Président de l'Association Espagnole des Ingénieurs de l'Aéronautiques; Colonel de Montravel, Etat-Major de l'Air; R. L. Ninnes, Esq., F.R.Ae.S., The Bristol Aeroplane Co. Ltd.; Amiral Nomy, Chef de l'Etat-Major de la Marine.

Monsieur Oestrich, Directeur Technique de la Sté Nle d'Etudes et de Constructions de Moteurs d'Aviation.

J. Lankester Parker, Esq., O.B.E., F.R.Ae.S., Director, Short Bros. and Harland Ltd.; Monsieur Potez, Directeur des Aéroplanes H. Potez; Monsieur Prillard, Directeur de la Sté A.M.A.

Monsieur Racine, Directeur des Relations Extérieures Sté Nle d'Etudes et de Constructions de Moteurs d'Aviation; Monsieur Richer, Directeur de Contrôle Sté Nle d'Etudes et de Constructions de Moteurs d'Aviation; Monsieur Riviere, Trésorier, Membre du Conseil A.F.I.T.A., Ingénieur à l'Office National d'Etudes et de Recherches Aéronautiques; Monsieur R. Robert, Directeur Technique de la Sté Gle de Mécanique Aviation Traction; Monsieur M. Roy, Directeur de l'Office National d'Etudes et de Recherches Aéronautiques, Membre de l'Institut.

Monsieur Savarit, Directeur de la Sté Morane-Saulnier; J. E. Serby, Esq., C.B.E., B.A., F.R.Ae.S., Deputy Director, Royal Aircraft Establishment; B. S. Shenstone, Esq., F.R.Ae.S., Chief Engineer, British European Airways; Air Commodore G. Silyn Roberts, C.B.E., A.F.C., F.R.Ae.S., D.D.R.D. Military Aircraft, Ministry of Supply; D. C. Smith, Esq., A.F.R.Ae.S., Royal Aeronautical Society; Group Captain L. S. Snaith, A.F.C., Royal Aircraft Establishment; Monsieur Szydlowsky, Président, Directeur Général de la Sté Turbomeca.

Monsieur Tendron, Secrétaire Général de l'A.F.I.T.A.; Geoffrey A. V. Tyson, Esq., A.F.R.Ae.S., Chief Test Pilot, Saunders-Roe Ltd.

C. F. Uwins, Esq., O.B.E., A.F.C., F.R.Ae.S., Honorary Treasurer, Royal Aeronautical Society, Managing Director (Aircraft Division) Bristol Aeroplane Co. Ltd.

Monsieur Valensi, Directeur de la Sté Mecanique des Fluides de Marseille; Général Vallin, Inspecteur Général de l'Armée de l'Air; Monsieur Verdurand, Directeur de l'Institut Français du Transport Aérien; Ingénieur Général Vernisse, Directeur de l'Arsenal de l'Aéronautique.

Ingénieur en Chef Wanner, Directeur du Service Technique au Ministère de l'Air; Colonel T. F. Weldon, United States Air Force, U.S. Embassy, London; Air Commodore Sir Frank Whittle, K.B.E., C.B., F.R.Ae.S., Technical Adviser on Jet Development, British Overseas Airways Corporation; J. Wright, Esq., F.R.Ae.S., Dunlop Rubber Co. Ltd.

The following day a visit was made to O.N.E.R.A., the French Aeronautical Research Organisation, which included the Wind Tunnels at Chalais-Meudon and the headquarters at Chatillon-sous-Bagneux.

Control Surface Flutter

by

E. G. BROADBENT, M.A., A.F.R.Ae.S.

and

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The 839th Lecture to be given before the Royal Aeronautical Society was delivered at the Institution of Civil Engineers, Great George Street, London, S.W.1, on the 20th December 1951. Mr. G. R. Edwards, M.B.E., F.R.Ae.S., Vice-President of the Society, presided and introduced the Lecturers, Mr. E. G. Broadbent, M.A., A.F.R.Ae.S., and Mr. W. T. Kirkby, A.F.R.Ae.S., A.M.I.Mech.E., of the Royal Aircraft Establishment.

PART I

Theoretical Background

1. INTRODUCTION

In recent years it has grown customary for aircraft firms to put increasing effort into the prediction of flutter during the design stage. This design work, however, is chiefly related to wing flutter in which the control surfaces play little part, whereas the cases of flutter which most commonly occur in reality are those involving control surfaces. The reason for this is that the wing stiffness, and hence the wing weight, is often determined by considerations of main surface flutter. Control surface flutter, however, can often be prevented by methods which do not have a serious effect on the aircraft weight and which are often postponed until after the design stage. This paper will discuss what steps can be taken, both in the design stage and during the flight testing of a prototype, to prevent control surface flutter. The field here is very wide, because of the variety of acceptable methods in control design, and of the many ways, for example by tabs and powered-operated controls, by which the pilot can be assisted in applying force. In many cases a set of calculations made in the late design stage would save valuable time and effort during the flight testing stage of the aircraft. A thorough knowledge of the flutter properties of the system, moreover, might help towards a much quicker cure of flutter or allied vibration, should either be met with in flight. In general, such calculations should cover a wide range of variables with a few degrees of freedom (binaries or ternaries), rather than take the form of a single involved calculation with many degrees of freedom intended to give one final answer. No matter how many calculations have been made, however, it is important to approach the flight testing of a prototype with an eye to the possibility of detecting incipient flutter. Arguments may be raised that anything in the nature of flight flutter testing is dangerous, but the point is that all aircraft are automatically flutter tested, in some degree, in the normal process of routine flying. Any warning of the onset of flutter is worth having, and in the authors' opinion, to obtain such warning should be a recognised objective in planning flight trials.

Mention must also be made (as many writers have done in the past) of the need for increased accuracy in obtaining the basic data. The two leading problems in this field are the determination of more accurate aerodynamic flutter derivatives, and improvement in the technique of resonance testing both of aircraft and controls.

NOTATION AND ABBREVIATIONS

ω flutter frequency
$\bar{\omega}_3$ tab natural frequency
I_c control surface inertia

V	forward true air speed
V_c	critical flutter speed
ρ	air density
$-H_{d\beta/dt}$	control surface aerodynamic damping coefficient
$-H_\beta$	control surface aerodynamic stiffness coefficient (involving the derivative $-h_\beta$ or $-b_2$)
E	elastic restraining stiffness of the control circuit
α	angle of incidence
β	deflection of control surface
γ	deflection of tab relative to control surface
l_β or a_2	non-dimensional derivative giving rate of change of lift with β
$m_{d\alpha/dt}$	non-dimensional derivative giving rate of change of moment about leading edge with rate of change of α
m_β, m	non-dimensional derivative giving rate of change of moment about leading edge with β
h_α or b_1	non-dimensional derivative giving rate of change of hinge moment with α
h_β or b_2	non-dimensional derivative giving rate of change of hinge moment with β
C/C_c	actual damping/critical damping
t_γ or c_3	non-dimensional derivative giving rate of change of tab hinge moment with γ
I_1, I_2	components of powered control circuit stiffness (*see* Part I, Section 5)
ν	non-dimensional frequency parameter
μ	non-dimensional parameter defining growth of amplitude (logarithmic decrement $= -2\pi\mu/\nu$)
N	spring- (or servo-) tab follow up ratio
I.A.S.	indicated air speed
E.A.S.	equivalent air speed

Strictly the term "critical damping," C_c, only has significance for motion in a single degree of freedom. It is convenient, however, to extend the idea to cover the decay of a more general type of motion, and in this case

$$\frac{C}{C_c} = -\frac{\mu}{\nu} = \frac{1}{2\pi}(\text{logarithmic decrement})$$

The displacement at any instant is proportional to $e^{(\mu+i\nu)r}$ where r is the non-dimensional time parameter = (time) × (forward speed)/(wing chord).

2. BASIC PROPERTIES OF CONTROL SURFACE FLUTTER

Before more detailed aspects of control surface flutter are discussed, it is convenient to review the general properties.

An important feature which should always be borne in mind when discussing control surface flutter is that prevention of flutter should be aimed at, irrespective of known flight limitations. This is a general precaution and is based on experience that the accuracy with which flutter can be predicted is much greater in terms of structural parameters (such as mass-balance) than in terms of air speed. It is not always possible to follow this rule, but with most simple designs it can be done.

The type of flutter first considered is that of a single flap mounted on a main surface. Flutter usually arises with one of two kinds of main surface motion and these two kinds are typified by wing-bending aileron flutter and wing-torsion aileron flutter. In wing-bending flutter the motion of wing chordwise sections is translational and of large amplitude at the aileron, giving considerable displacement to the aileron hinge line. In wing-torsion flutter the motion of wing chordwise sections is pitching in character, and the aileron hinge displacement is much less. These two different kinds of flutter have certain distinct characteristics. Wing bending is a type of motion which is heavily damped aerodynamically and this gives rise to a large positive damping determinant in the bending-aileron flutter equations. In these circumstances flutter can arise only from a powerful source of excitation. This source exists if the aileron centre of gravity is well aft of the hinge line as this permits the powerful lift term from the aileron (l_β or a_2)* to excite the wing motion. On the other hand this coupling, and with it the existence of flutter, is readily destroyed if the aileron centre of gravity (including virtual inertia effects) is brought up to the hinge line.

In torsion-aileron flutter the position is no longer a clear fight between two powerful adversaries. The damping determinant is now comparatively small, but so also is the source of excitation. These two effects can

*The flutter derivative is quoted first, followed by its equivalent stability derivative which, although less descriptive, may be more familiar to some.

be seen by the fact that the two-dimensional incompressible value of the wing torsional (aerodynamic) damping ($-m_{d\alpha/dt}$) vanishes altogether if the nodal line runs at the three-quarter-chord position, and also the exciting term ($-m_\beta$ or m) vanishes if the nodal line runs at about the half-chord position. Thus, as compared with bending-aileron flutter, it is not so easy to say in advance whether torsion-aileron flutter will occur or not. A further complication is that torsion-aileron flutter occurs, if at all, at a higher speed than bending-aileron flutter, but it is then more difficult to suppress because the inertia coupling is less sensitive to mass-balance.

Fuselage-bending elevator flutter is related to both kinds of wing-aileron flutter. If the node in the fuselage is well forward then it is more akin to bending-aileron flutter, whereas if the node is far back it is similar to torsion-aileron flutter. Similarly with rudder flutter the fuselage and fin nodal points can vary in such a way as to give either kind of flutter.

In spite of the differences between these two kinds of flutter, a number of parameters can be shown to have similar effects on each. These effects are now described briefly.

2.1. Variations of Control Surface Inertia and Stiffnesses

Figure 1 shows a typical diagram of flutter speed plotted against control surface inertia. Suppose curve (*a*) is for a control surface without mass-balance. If the moment of inertia alone is increased from zero (a constant mass-moment is implied, not a constant c.g. position), there is at first a region of complete immunity from flutter. This is followed by a region in which flutter starts at a lower critical speed and then dies out at a higher critical speed, possibly to be followed at still higher inertias by a region in which there is no upper critical speed. In practical cases a large inertia is a bad thing, for although the lower critical speed may rise a little with increase in inertia, it is likely to remain within the flying speed range of the aircraft, and the severity of the flutter gets worse as the upper and lower critical speeds become more widely separated.

Curves (*b*) and (*c*) show the effect of reducing the product of inertia between the motions of the control surface and the main

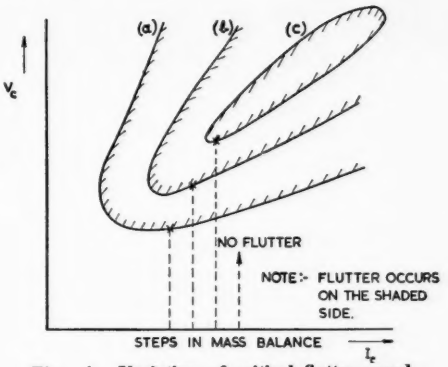

Fig. 1. Variation of critical flutter speed with control surface moment of inertia.

surface. The effect is strongly stabilising. Mass-balance of the control surface normally achieves this effect, although at the same time it increases the moment of inertia, and flutter is eventually eliminated altogether.

Consider now the variation of the control surface moment of inertia. The control surface forces due to control surface motion may be written as

$$\{ -I_c\omega^2 + (-H_\beta)\rho V^2 + E \}\,\beta\cos\omega t + \\ + (-H_{d\beta/dt})\rho V\omega\beta\sin\omega t \quad . \qquad (1)$$

From this set of forces it can be seen that an increase in I can be compensated for by a decrease in E, and *vice versa*. Thus the effect of increase in the circuit restraining stiffness can be seen by moving to the left

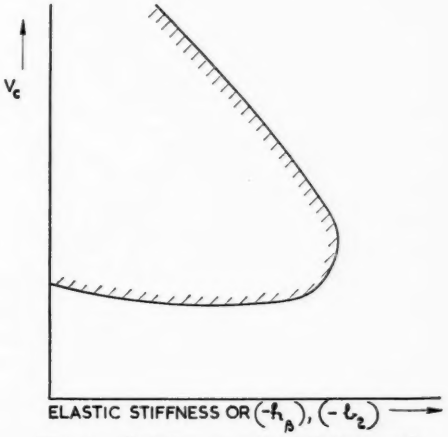

Fig. 2. Variation of critical flutter speed with control circuit stiffness.

in Fig. 1; flutter is eventually eliminated. Furthermore, an increase in $(-h_\beta)$ or $(-b_2)$ has an effect similar to an increase in circuit stiffness, and opposite to an increase in control surface inertia. By analogy it is to be expected that for flutter of the torsion-aileron type, an increase in $(-h_\alpha)$ or $(-b_1)$ would have an effect similar to an increase in mass-balance, and in particular that a positive h_α or b_1 would have a very bad effect. In a particular case in which this was investigated the range of flutter was considerably increased by a reduction in $(-h_\alpha)$, but the lower critical speed was also raised.

Special mention should be made of very large or very heavy control surfaces, for which flutter is often difficult to suppress. It is the relative density of the control surface to the air which is important here, and an increase in altitude has the same effect (at constant equivalent air speed and neglecting compressibility) as an increase in mass of the control surface. For example, a curve of the type shown in Fig. 2 can take the form of Fig. 4 in such cases. In Fig. 4 the flutter speed rises steadily with increasing stiffness and tends to an infinite speed for an infinite stiffness, but there is no upper bound to the flutter. Fig. 4 neglects the possibility of flutter of the main surface itself; if this has a real flexure-torsion flutter speed, for example, the curve of wing-aileron flutter speed will tend asymptotically to this value.

2.2. Variations in control surface damping

Increase in damping can also be used to suppress flutter, as shown in Fig. 5. Normally with sufficient damping a condition is reached for which no flutter occurs but, again, for very heavy controls or at great heights, this is not possible. In this case the effect of increase in height is to be expected, for if the equivalent air speed is maintained constant, it can be seen from the expression (1) that the damping term is reduced by comparison with the others as the air density falls.

3. The Importance of Modal Shape

It has long been recognised that the shape of the aircraft normal mode in relation to the control surface mass-balance weights is an important feature in deciding whether flutter will occur or not. The resonance test results are examined chiefly with the idea of deciding which modes are bad, and which good, from this aspect. It is current practice to make flutter calculations with the bad modes, but to pass over the good modes on the assumption that flutter will not occur.

3.1. Control surfaces with leading-edge mass-balance

The best way of avoiding trouble from control surface flutter is still to distribute the

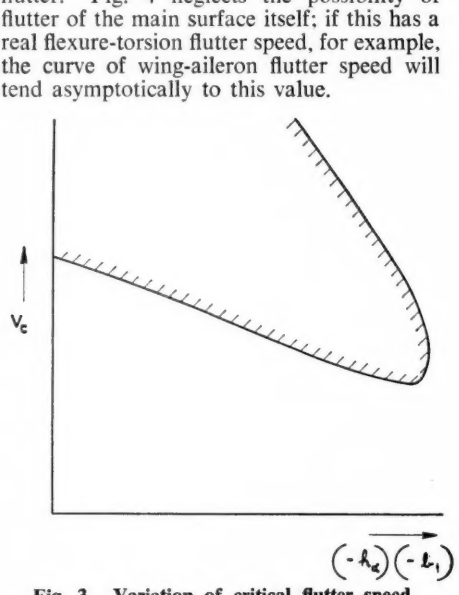

Fig. 3. Variation of critical flutter speed with $(-h_\alpha)$.

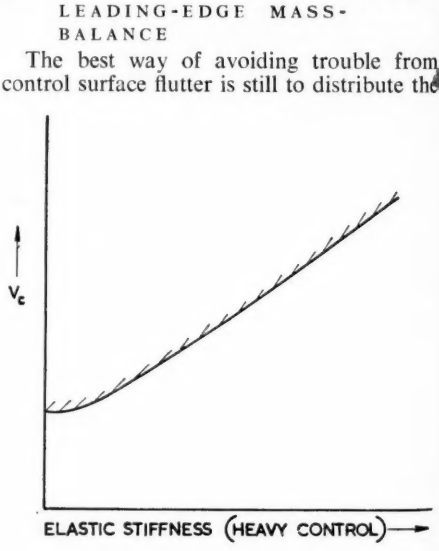

Fig. 4. Variation of critical flutter speed with control circuit stiffness for a heavy control surface.

mass-balance evenly along the leading edge. Instances of control surface flutter with this type of mass-balance are extremely rare (unless influenced by the presence of another degree of freedom), and that fact alone should be a sufficient recommendation. Nevertheless the possibility of flutter does exist and it is important to know what features to look for in the resonance test results. It is assumed that the control surface is about statically balanced. For an aileron the most dangerous type of mode is one in which the nodal line runs along or near the wing leading edge. For elevators and rudders much the same applies except that in a dangerous mode the nodal line lies a little ahead of the (tailplane or fin) leading edge.

With such a mode it is possible that static balance will be insufficient to eliminate flutter, but fortunately modes of this type are rare. It is certainly uncommon for a wing nodal line to run along the leading edge, and the chief danger lies in fuselage bending modes of the type that have a nodal point well back in the fuselage, say, just ahead of the tailplane leading edge. These modes are common enough but fortunately are usually associated with considerable tailplane bending, as it is unusual for tailplane and fuselage bending frequencies to be widely different. In fact the tailplane usually behaves as shown in Fig. 6(*a*), where the bending pushes the nodal point of tailplane sections farther forward in going from root to tip. If the tailplane is actually resonating at this particular frequency it will behave as in Fig. 6(*b*), where the bending is even more favourable and balances the inboard half against the outboard half. A mode of the type shown in Fig. 6(*c*) is physically impossible, since the tailplane tip conditions are not satisfied. If two modes such as 6(*a*) and 6(*b*) occur close together in frequency, then the possibility of ternary flutter (in which the tailplane bending is cancelled out) must be considered. Rudder flutter is subject to much the same conditions as elevator flutter.

3.2. Control Surfaces with Concentrated Mass-Balance Weights

Usually the ideal of distributed mass-balance is difficult to achieve because of stowage problems, particularly if there is no forward aerodynamic balance, or if the balance is Irving-type in a thin section. In such cases concentrated balance weights may have to be adopted; in other cases they are used as being more convenient, or in order to save weight.

Ailerons are often mass-balanced by a concentrated weight and this is usually placed at the tip to save weight. This scheme is almost always satisfactory in practice and it is difficult to imagine a modal shape which would seriously reduce the effectiveness of such a mass. It is possible, however, that the presence of a wing tip tank (or similar mass) might give rise to a mode which would embarrass the tip weight. A more serious

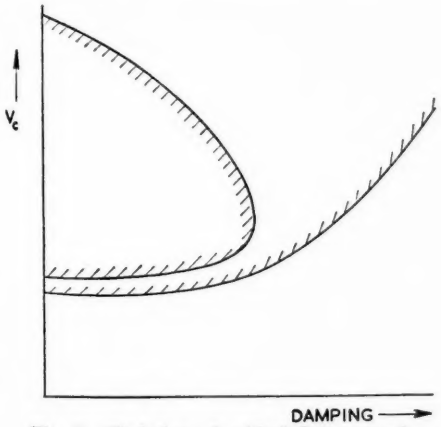

Fig. 5. Variation of critical flutter speed with artificial damping.

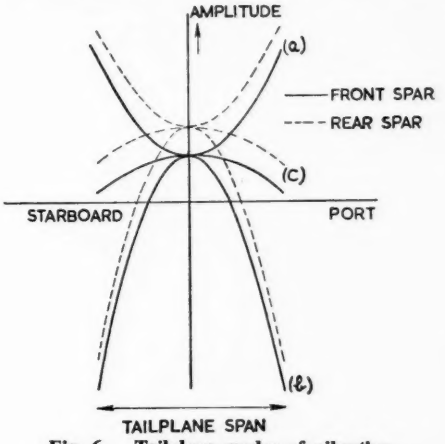

Fig. 6. Tailplane modes of vibration associated with fuselage flexure.

danger exists if the concentrated weight is placed near the inboard end of the aileron; the fundamental anti-symmetric wing bending mode is bad for this type of mass-balance.

Elevators have been the chief source of control surface flutter incidents in recent years, and one of the main reasons has been the use of concentrated balance weights. It is undoubtedly convenient to split the elevator mass-balance into three parts, and to place part in each elevator horn with the remainder in the fuselage. This scheme of mass-balance is probably more common than any other for elevators. Superficially it appears to do its job adequately, since it provides mass-balance against both vertical translation of the tailplane and roll of the tailplane, and as the mass involved is small because long balance arms are available, the arrangement is a popular one; but it leaves some common types of mode unprovided for. It is worse than distributed mass-balance for a fuselage bending mode with a "rigid" tailplane (admittedly uncommon), simply because the mass-balance arms are longer, and the weights are therefore nearer the node. It is also unsatisfactory for tailplane bending modes of the type shown in Figs. 7(*a*) and 7(*b*).

Figure 7(*a*) shows a symmetric mode which could couple with elevator rotation, and in this mode the horn balance weights are acting the wrong way for the greater part of the elevator. It is possible that the centre-line weight, in spite of its full effectiveness, will be inadequate to suppress the flutter. Fig. 7(*b*) shows an anti-symmetric mode, and again the horn weights act the wrong way. In this case, as with all anti-symmetric modes the centre-line weight has no effect at all; on the other hand the two halves of the elevator have to twist against each other, and this motion is normally resisted by the torsional stiffness of the elevator itself and a stiff interconnection. If the elevator torsional frequency (one half against the other) is high, then the flutter speed associated with this type of mode will also be high. It may occur, however, within the flying speed range of the aircraft, and if so the flutter is likely to take a dangerous form because of the high stresses near the horn.

Remote mass-balance has often been tried, usually for elevators. It enables the weight to be stowed away inside the fuselage, but the arrangement is not recommended as it is unlikely to be effective against all modes of vibration. The practice of relying entirely on remote weights for mass-balance has now died out, but the central weight of three on the elevator, or the bottom weight of two on the rudder, is sometimes remotely attached. If remote weights are used it is important to make sure that the flexibilities of the various arms in the linkage are not badly proportioned.

Like the elevator, the rudder is also difficult to mass-balance adequately with concentrated weights. In addition it is more difficult to pre-judge the result of flutter calculations on the rudder than on any of the other control surfaces. Flutter calculations on the rudder will often suggest that no mass-balance is needed in spite of a bad nodal line; this is usually caused by heavy aerodynamic damping of the associated wing and tailplane motion. The occurrence of rudder flutter in flight,

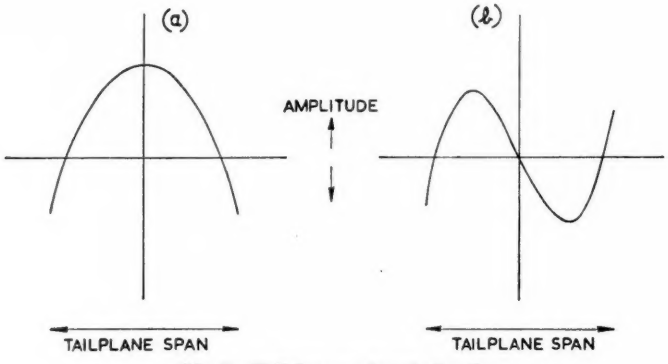

Fig. 7. Tailplane modes of vibration.

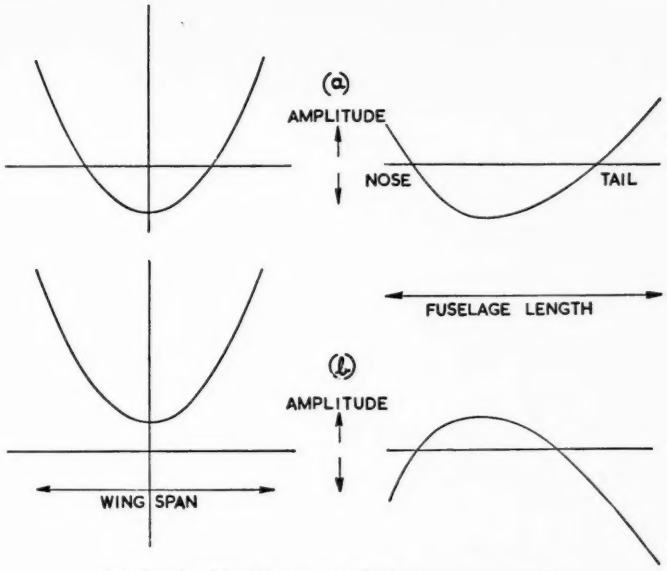

Fig. 8. Combined fuselage and wing resonance modes.

however, is not unknown, even in recent years. Distributed mass-balance is the best safe-guard.

3.3. Some complications that can arise

Reference has already been made to the possibility of two normal modes combining together in flight in such a way as to give a mode more dangerous than either of the originals. A way in which this might lead to elevator flutter is indicated by Fig. 8. This shows two symmetric normal modes ((*a*) and (*b*)) near together in frequency with the wing amplitudes plotted on the left and the fuselage amplitudes plotted on the right. Either of these modes might give rise to elevator flutter, because of the aft nodal point in the fuselage, were it not for the heavy aerodynamic damping to be expected on the wing. If, however, the two modes combine, in flight, by direct subtraction (as plotted in Fig. 8), the wing motion will be greatly reduced without affecting the fuselage amplitudes. This possibility makes flutter much more likely. The same effect might occur in a more complicated way if the tailplane also resonated at a frequency near to those of the wing and fuselage, when three modes would be involved. The proper way to deal with these problems in analysis is to add an extra degree of freedom for each mode, but a short cut (first suggested by Professor Collar) can sometimes be employed. The short cut consists of combining the two modes together so as to make the wing motion a minimum, and the inertia and elastic coefficients of the combined mode can then be calculated in terms of the known values for the original mode.

Another complication that arises with normal modes of the type shown in Fig. 8, is that the aerodynamic forces on the tailplane, during oscillations in flight, will be affected by the wing motion. D. E. Williams, at the Royal Aircraft Establishment, is making an investigation into the importance of this effect. The conclusions he has drawn from a binary investigation are, that if the wing amplitude is large enough to make an important change in the tailplane derivatives, then it will be so large that the aerodynamic damping on the wing will dominate the flutter, and only a small change in the (flutter speed)-(mass-balance) curve is to be expected.

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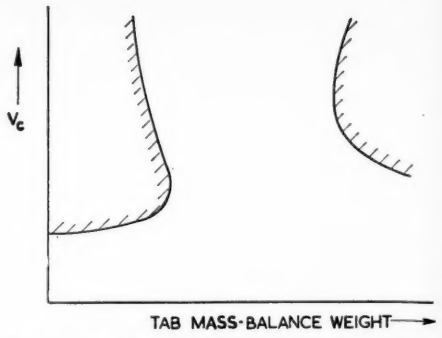

Fig. 9. Variation of critical flutter speed with tab mass-balance weight.

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6. CASES OF LOW DAMPING NEAR TO FLUTTER

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danger exists if the concentrated weight is placed near the inboard end of the aileron; the fundamental anti-symmetric wing bending mode is bad for this type of mass-balance.

Elevators have been the chief source of control surface flutter incidents in recent years, and one of the main reasons has been the use of concentrated balance weights. It is undoubtedly convenient to split the elevator mass-balance into three parts, and to place part in each elevator horn with the remainder in the fuselage. This scheme of mass-balance is probably more common than any other for elevators. Superficially it appears to do its job adequately, since it provides mass-balance against both vertical translation of the tailplane and roll of the tailplane, and as the mass involved is small because long balance arms are available, the arrangement is a popular one; but it leaves some common types of mode unprovided for. It is worse than distributed mass-balance for a fuselage bending mode with a "rigid" tailplane (admittedly uncommon), simply because the mass-balance arms are longer, and the weights are therefore nearer the node. It is also unsatisfactory for tailplane bending modes of the type shown in Figs. 7(*a*) and 7(*b*).

Figure 7(*a*) shows a symmetric mode which could couple with elevator rotation, and in this mode the horn balance weights are acting the wrong way for the greater part of the elevator. It is possible that the centre-line weight, in spite of its full effectiveness, will be inadequate to suppress the flutter. Fig. 7(*b*) shows an anti-symmetric mode, and again the horn weights act the wrong way. In this case, as with all anti-symmetric modes the centre-line weight has no effect at all; on the other hand the two halves of the elevator have to twist against each other, and this motion is normally resisted by the torsional stiffness of the elevator itself and a stiff interconnection. If the elevator torsional frequency (one half against the other) is high, then the flutter speed associated with this type of mode will also be high. It may occur, however, within the flying speed range of the aircraft, and if so the flutter is likely to take a dangerous form because of the high stresses near the horn.

Remote mass-balance has often been tried, usually for elevators. It enables the weight to be stowed away inside the fuselage, but the arrangement is not recommended as it is unlikely to be effective against all modes of vibration. The practice of relying entirely on remote weights for mass-balance has now died out, but the central weight of three on the elevator, or the bottom weight of two on the rudder, is sometimes remotely attached. If remote weights are used it is important to make sure that the flexibilities of the various arms in the linkage are not badly proportioned.

Like the elevator, the rudder is also difficult to mass-balance adequately with concentrated weights. In addition it is more difficult to pre-judge the result of flutter calculations on the rudder than on any of the other control surfaces. Flutter calculations on the rudder will often suggest that no mass-balance is needed in spite of a bad nodal line; this is usually caused by heavy aerodynamic damping of the associated wing and tailplane motion. The occurrence of rudder flutter in flight,

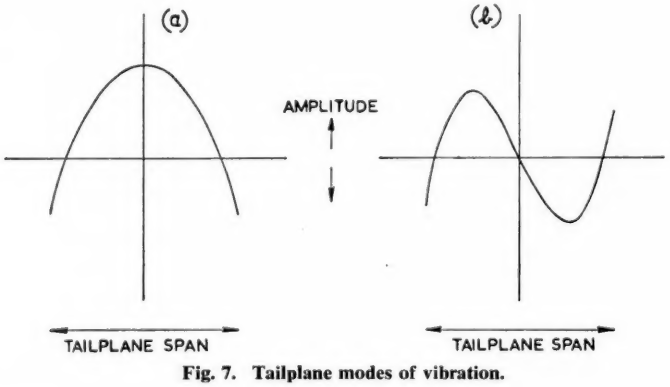

Fig. 7. Tailplane modes of vibration.

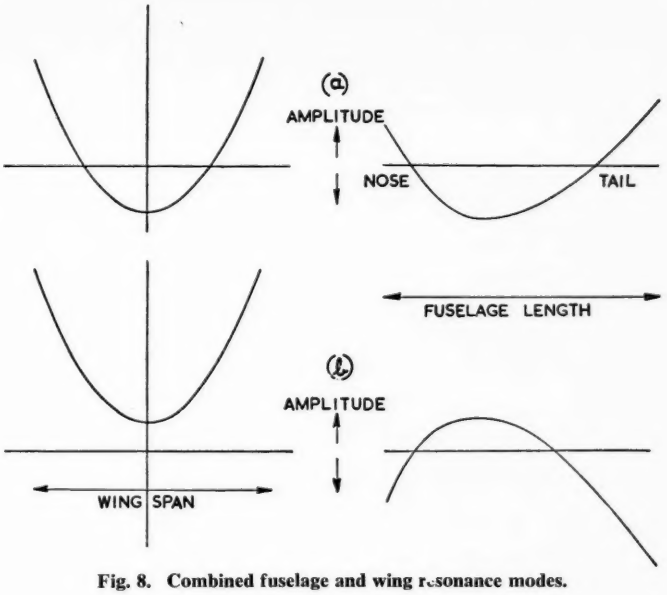

Fig. 8. Combined fuselage and wing resonance modes.

however, is not unknown, even in recent years. Distributed mass-balance is the best safe-guard.

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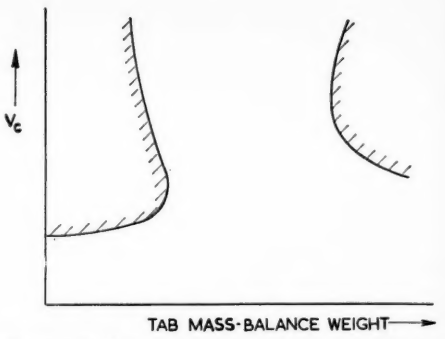

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the critical region (*AB* in Fig. 10). It is likely that considerable improvement would be gained by increasing the elevator mass-balance.

While a reduction of damping is often possible in this way it is not always easy to find in practice. First must come some indication of where the basic fault lies; this may be quite apparent, such as pronounced control surface or tab amplitude in the vibration. Then steps must be taken to try to increase the margin from flutter, and with tab systems, particularly, this may be difficult to do because of the two types of tab flutter. Modifications which may succeed include changes in tab mass-balance, tab aerodynamic balance, tab follow-up ratio and control surface natural frequencies, and the addition of trailing-edge cord to the tab; but it is often a thankless task to try out these variations in flight, one after the other, with no theoretical guidance and, where possible, ternary calculations should precede any flight changes, although flight measurements should be made as soon as possible. An important point is that the basic data should be correctly known at the start of the work. Too often a quick cure is hoped for and one or two modifications are tried. This leads further, and before long a large programme of flight work has been started which may well lead nowhere; it may even prove to have been carried out on the wrong control surface (this has happened in practice). Much of this can be avoided if accurate ground resonance test results and accurate flight measurements are available at the start of the investigation. If the vibration is felt on the control column or rudder bar, then the circuit may be having an important effect, and its characteristics should be determined. It may have a large effect on the pilot's impressions, besides being important in its own right.[4]

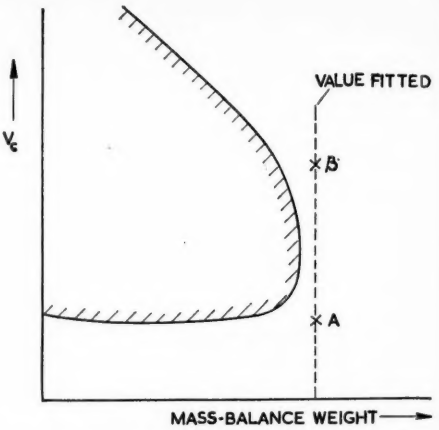

Fig. 10. Flutter curve which extends too close to amount of mass-balance fitted.

7. THE EFFECTS OF COMPRESSIBILITY

There are two effects of compressibility. One is the steady change in derivatives with increasing Mach number in the absence of shock waves, and the other is the presence of shock waves themselves. Little is known about either. Some theoretical calculations have been made to compare the effects of high and low Mach number derivatives (linearised two-dimensional theory was used) on flutter speed, but the results are inconclusive. On the whole they show a slight improvement with increasing Mach number. On the other hand, the two-dimensional theory may be badly out, particularly in calculating hinge moments at high Mach numbers. Certainly the variations in static hinge moment derivatives with Mach number, are often quite different from two-dimensional predictions, and sometimes suggest a greater likelihood of flutter at high Mach numbers.

The presence of shock waves can lead to " compressibility flutter " or " control surface buzz," in which growing oscillations of the aileron, for example, can occur without any wing motion. There is nothing new to report in this field; thin sections, low trailing-edge angle, maximum thickness well forward and small control surface chord are all beneficial. The structural parameters are not very important in this type of flutter, but high control circuit stiffness is generally good.

8. FLIGHT FLUTTER TESTING

Part I of this paper gives an outline of the difficult problems of control surface flutter and the current theoretical ideas for tackling them, but no amount of theory will guarantee that an aircraft is perfectly safe to fly and in the last resort some form of flight test is necessary. For research work, an elaborate flight flutter technique can be developed and this should go hand-in-hand

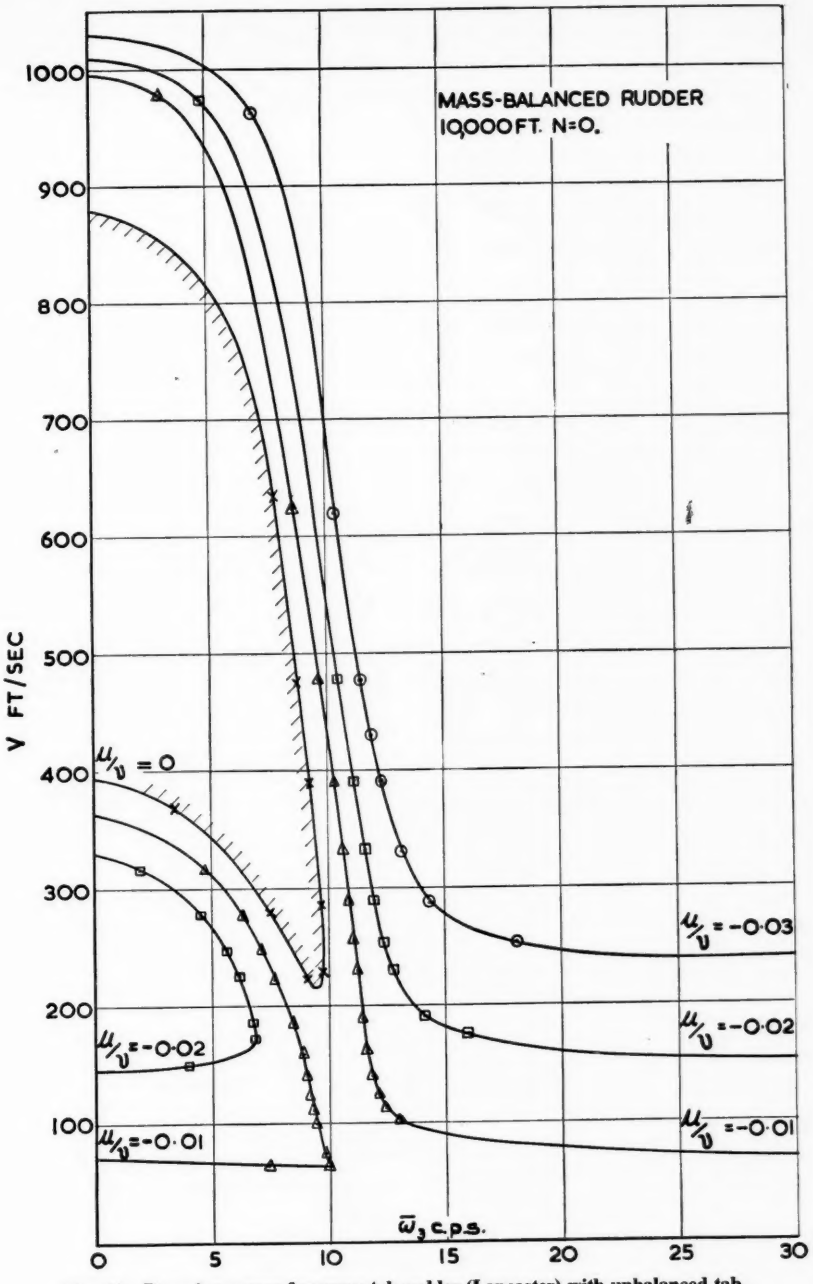

Fig. 11. Damping curves for servo-tab rudder (Lancaster) with unbalanced tab.

with elaborate calculations. It is useful to make calculations of this nature for different rates of decay (or growth) of the suspected oscillations, and an example is given in Fig. 11, which is for the Royal Aircraft Establishment servo-tab Lancaster with no mass-balance on the rudder tab. Speed is plotted against the natural frequency of the tab on its circuit for different rates of decay. The accompanying flight work has not yet been started because of an accident to the aircraft.

Such a long programme is neither necessary nor desirable to clear each new prototype, but something more than merely flying the aircraft hopefully should be attempted. The possibilities are discussed in detail in the second part of the paper, but it may be remarked here that the work can be helped along by knowing the theoretical background of the types of flutter that may occur. This is where a few general calculations done in the design stage are useful.

PART II

Flutter Clearance Tests in Flight

1. INTRODUCTION

It has been indicated in Part I that there may be considerable errors in the attempts to predict flutter of aircraft controls from theoretical calculations. The development of the theoretical approach to flutter problems has been seriously hampered by the fact that little experimental full-scale evidence has been obtained to substantiate the theoretical work. Much of the evidence that has been obtained has been of a negative nature, *i.e.* no flutter has been predicted and no flutter incident has occurred. In the cases where flutter has occurred, it has often occurred in degrees of freedom not considered in the pre-flight calculations and has not always lent itself to theoretical explanation.

There are two main aspects of full-scale flutter experiments. First, experiments forming part of a general research programme intended to check the validity of the appropriate theoretical calculations, and also intended to fill some of the gaps in existing knowledge by supplying information on modes in flight, and Mach number effects. Second, flight experiments to form part of the development flying programme on prototype aircraft, or aircraft to which changes have been made which may affect the flutter conditions (*i.e.* tip tanks, external stores, modifications to control circuits).

In the space available it is not possible to cover both the foregoing aspects and this part of the paper is concerned primarily with the flutter clearance tests made during the normal test and development flying period of a particular type of aircraft.

In the past, many flutter incidents have occurred in the course of test flying, often when some other flight characteristic of the aircraft was being investigated. Such incidents have usually occurred when the aircraft has exceeded the speed attained in previous flights, although a few incidents have occurred when flying in bumpy weather, at a speed less than the previous maximum, or at higher altitudes. These incidents have rarely been catastrophic, although in some cases there has been structural damage, but in any case they have an adverse effect on the morale of the crew of the aircraft. Fortunately the linearity of coefficients that has to be assumed to make the theoretical calculations manageable is not realised in practice, otherwise most of the incidents would have been divergent and consequently disastrous. It is clearly desirable to adopt a flight technique which will indicate the approach to a flutter condition and thus lessen the risks to the crew and the aircraft. It is appreciated that the aircraft manufacturers already have formidable flight test programmes and that any further additions are unwelcome, but it is suggested that flutter check tests can substantially reduce the risk of an unforeseen flutter incident occurring, often without much additional flying and with simple instrumentation. Often it may be possible to carry out the flutter clearance tests in the course of flights forming part of the general test and development programme.

It is only in comparatively recent years that serious consideration has been given to flight flutter testing of a routine, rather than of a research, nature and consequently there is a lack of the background of experience and period of development that is available in many other fields of flight testing. The

methods that are now considered represent present views, which may well be modified as further experience is obtained and as development proceeds.

2. FLUTTER CLEARANCE TESTS IN FLIGHT

2.1. General method

The principle underlying all test methods is to excite the flutter modes of the aircraft from a controllable energy source beginning at an air speed well below the maximum air speed, or calculated critical flutter speed, and to measure the response of the aircraft to the known energy input at increasing air speeds. The air speed is increased in small steps until the maximum permissible speed of the aircraft is achieved, or until the response to the input energy shows that a flutter condition is being approached. In the general case it is desirable to excite all modes of the aircraft to ensure that the flutter modes are not missed; in the particular case, attention may be focused on a mode which may be suspect from the flutter point of view.

Two methods of exciting the aircraft modes are considered in this paper:—

(*i*) *Forced vibration*

A sinusoidal force of variable frequency is applied to the aircraft structure or controls, as in ground resonance testing.

(*ii*) *Transient response*

A manual "jerk" is applied to the controls of the aircraft which will excite transient response in several modes at the same time. The degree of forcing of each mode, resulting from the jerk, will depend on the shape of the force/time curve and it is theoretically possible to excite all the relevant structural modes by this method.

The response of the aircraft structure to the energy input at each increment of air speed is determined from the damping in the modes. The value of the damping may be obtained from the resonance curves or from the decay oscillations, depending on which method of excitation is used. This damping value, which includes the aerodynamic and structural terms, may be plotted against the equivalent air speed and the approach to a flutter condition will be indicated by an adverse change of slope of the curve or approach of the damping to zero.

The general method just outlined is not original. It has been developed from methods suggested by von Schlippe, who proposed measurement of amplitude response to continuous forcing[5], and Grossman who advocated measurement of damping in decay oscillations. A preliminary investigation, in which the damping measured from decay oscillations, excited by manual jerking methods, was compared with theoretical damping values, was reported by Rosenbaum and Scanlan[6] in 1948. The method of Ref. 6 has subsequently been used with success both in this country and the United States. In certain cases the manual "jerk" method is not satisfactory and the general problem of excitation of the aircraft modes is now examined briefly.

2.2. Excitation of aircraft modes

Experience has shown that control surface flutter does not occur at frequencies higher than five to six times that of the lowest structural frequency and it is not considered necessary to excite frequencies higher than this during the flutter clearance tests. The various methods of excitation which have been considered are summarised in Fig. 12.

(*i*) *and* (*iii*) *Inertial excitation of aircraft structure or control surfaces*

This method is used generally in ground resonance testing and has been adequately described elsewhere[7]. Care must be taken to ensure that the mass of the exciter and associated driving equipment does not alter appreciably the modes of the aircraft. If possible the exciter should replace a piece of aircraft equipment of equivalent mass. The disadvantage of inertial exciters becomes apparent at very low frequencies when an extremely large amount of out-of-balance is required to produce the desired force and the weight of the exciter becomes prohibitive. For this reason inertial exciters would seldom be used to excite frequencies below approximately 3 cycles/sec. When such exciters are fitted in control surfaces, care should be taken to ensure that the control surface mass balance and inertia conditions are not seriously affected.

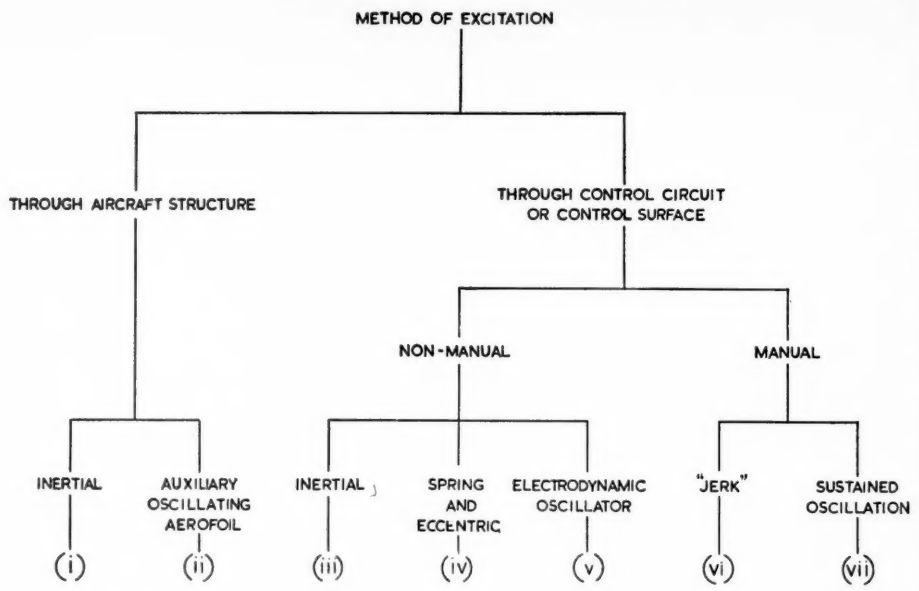

Fig. 12.

(*ii*) *Excitation of aircraft structure by oscillating auxiliary aerofoil*

In this method an auxiliary aerofoil of symmetrical section is attached externally to the aircraft structure and a sinusoidal change of incidence, of variable frequency, is forced through a linkage. So far as is known this method has not been tried in flight, but a preliminary design study has been made at the R.A.E., from which it appears that the scheme may be practicable for frequencies from 5 cycles/sec. down to zero. The disadvantages of this method are that the force produced varies approximately with the square of the air speed and also that it is difficult to position the aerofoil so that the air flow round the lifting and control surfaces of the aircraft is unaffected by the proximity of the aerofoil. Because of the complexity of the installation it is probable that this method is better suited to long-term research investigations than to tests of a routine nature.

(*iv*) *Excitation of control circuit by spring and eccentric*

Although attractively simple, this method of excitation suffers from the inherent disadvantage that the spring, in effect, links the control circuit to the airframe and consequently the dynamic characteristics of the control circuit will be altered. Flutter calculations would be necessary before using this method of excitation on a particular type of aircraft in order to assess the probable effect of the change of dynamic characteristics on the results of the flight tests.

(*v*) *Excitation of control circuit by electrodynamic exciter*

In this method an electrodynamic exciter of the moving-coil type, supplied by a variable frequency alternating current, is attached to the control circuit and aircraft structure. The particular advantages of this system are that force, amplitude and frequency are easily controlled in flight and an almost instantaneous cut-off of exciting force is possible. It should be remembered, however, that electrical impedance of the exciter will affect the dynamical impedance of the control circuit to some extent, although it is thought that this effect will not seriously prejudice the method of excitation.

(*vi*) *Manual excitation by jerking the aircraft controls*

As discussed before, this method has been used with success both here and in the United States and it is suggested that, despite some disadvantages, it is a satisfactory method of excitation for aircraft other than those fitted with powered flying controls. Experience has shown that the majority of relevant modes of a particular aircraft can be excited by jerking the aileron, elevator or rudder controls as appropriate. Fig. 13 shows records obtained by this method on a jet fighter aircraft. Undoubtedly in using the "jerk" there is some risk of failing to excite the critical flutter mode, but it is felt that the extreme simplicity of the method justifies its adoption as a standard method of excitation.

(*vii*) *Manual excitation by oscillating the aircraft controls*

This method has been tried, but in the authors' view it is not very satisfactory. The frequency of excitation is limited by the human element to a maximum of approximately 5 cycles/sec. Furthermore, it appears difficult for the pilot to vary the force applied to the controls without also altering the frequency. The tendency appears to be to lower the frequency when endeavouring to increase the force and therefore it is difficult for the pilot to control, with any certainty, either the frequency or the amplitude excited. The method cannot be entirely dismissed, however, since it has been used with success in the United States during flutter tests on a large bomber aircraft.

None of the methods of excitation through the control circuit mentioned here is considered satisfactory for aircraft fitted with powered flying controls, because the dynamic characteristics of these controls are such that neither continuously forced oscillations having sufficiently high frequencies, nor sufficiently "sharp" jerks, can be transmitted from the input end to the output end of the circuits. The only systematic methods appear to be excitation of the airframe to produce inertia and aerodynamic forces on the control surfaces, or the use of inertia exciters on the control surfaces themselves. If such methods are considered to be too complicated, the only alternative suggested by the authors is deliberately to fly the aircraft through "bumps" with increments of air speed and to take recordings of the resultant oscillations as in the general method. Such a technique, although better than no flutter tests at all, is obviously far from satisfactory and the development of some simple and reliable method of excitation of powered flying controls is considered to be a major outstanding problem.

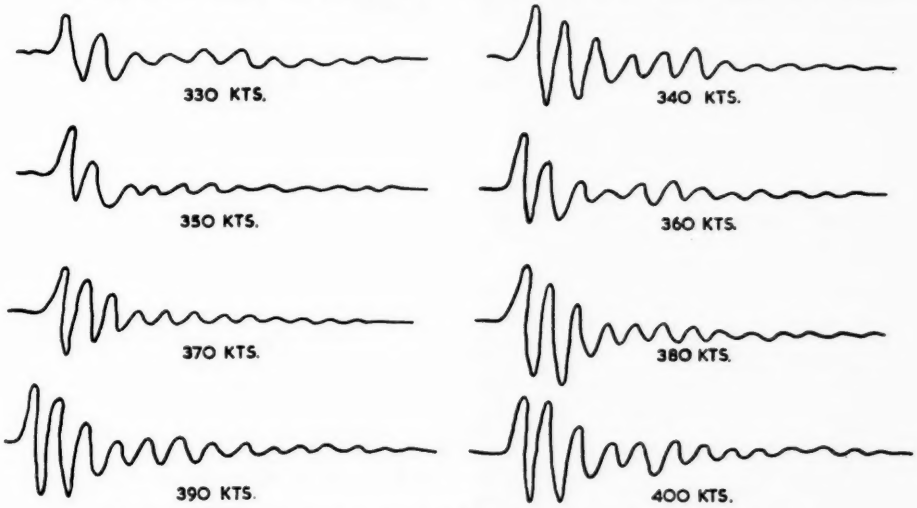

Fig. 13. Waveforms obtained from stick "jerk" tests on a jet fighter aircraft.

Consideration of excitation methods should not be concluded without reference to a recent American proposal[8] in which it is suggested that transient response of the aircraft structure could be excited by small rocket charges set in the surface of the structure. By altering the geometrical shape and burning characteristics of the charge particular force/time functions can be applied. So far as is known, this method is at present being developed and no flight trials have yet been made.

2.3. Recording Equipment

It is suggested that simple vibration recording instruments, such as the R.A.E. Mk. II vibrographs, should be fitted when the control jerking method of excitation is being used. It is advisable to use three such instruments to record the vibration vertically in the outer wing, and vertically and laterally in the tail unit, to minimise the possibility of overlooking a mode in which the damping is low.

If, during the subsesquent flight tests, a condition of low damping is encountered which necessitates investigation before proceeding to higher air speeds, it is strongly recommended that multi-channel recording equipment be fitted at this juncture to establish the structural mode and control surface motion directly in flight. The alternative process of embarking on flutter calculations using the frequency recorded in flight and the appropriate ground resonance tests modes has led to much exhausting and fruitless effort in such situations in the past. Multi-channel electronic equipment made in miniature is at present being developed for use in small aircraft in the foregoing circumstances.

If the continuous excitation technique is being used it is worth while to fit multi-channel recording equipment from the start. The additional amount of work involved is probably small compared with the work involved in the fitting of the continuous excitation equipment, and it is possible to obtain more accurate measurements of damping in the different modes encountered in the frequency range. Considerable effort is at present being put into the development of equipment which will permit direct measurement of the amplitude of the vibration having the forcing frequency only, so that the superimposed vibrations originating from the power plant(s) and aerodynamic "hash" are not recorded. In the meantime much can be done to eliminate unwanted frequencies by the use of electronic filters.

2.4. Analysis of Results

The results are analysed with a view to presenting curves of damping against air speed for the modes excited. The particular method of expressing the damping is not important but it has been found convenient to use the damping ratio C/C_c (=actual damping/critical damping) as found from the resonance or decay curves. It is unnecessary to plot damping curves for values of C/C_c greater than 0.05, which experience has shown to be the value in a reasonably damped mode.

The main difficulty that arises in trying to obtain reliable damping values from the flight test records is caused by the unwanted vibrations, some fairly continuous and some of a transient nature, which are forced by power plant vibrations, aerodynamic "hash" and "bumps." As mentioned elsewhere in this paper much can be done to alleviate these problems by forcing relatively large amplitudes and by electronic filters. If continuous excitation is being used the problem is simplified somewhat, because the knowledge that the amplitude associated with the forcing frequency is constant for that particular recording enables the usual graphical analytical methods to be applied. When the decay oscillation records are obtained the problem is more serious, particularly when the damping is comparatively high. If the damping is comparatively low it is possible to average successive logarithmic decrement values from peak to peak in the decaying oscillation. It is probable therefore that greater accuracy is obtained when the damping is low than when the damping is high.

2.5. Flight Procedure

2.5.1. *Range of air speed and Mach number*

As explained in Part I, control surface flutter is affected by equivalent air speed (E.A.S.) and Mach number, among other variables. For these two particular variables, it would therefore be ideally desirable to cover all combinations of E.A.S. and Mach number that could occur. The amount of flight testing required to approximate to this

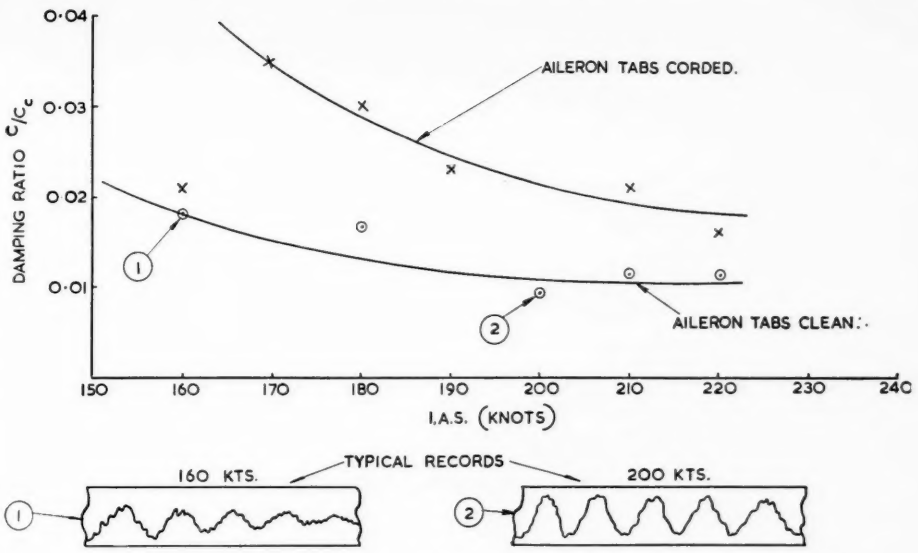

Fig. 14. Damping/air speed curves obtained on an aircraft having servo-tab controls.

ideal condition is obviously prohibitive and experience suggests that the best compromise is to cover the range of equivalent air speeds at the greatest height at which the maximum E.A.S. can be attained.

2.5.2. *Selection of air speed increments*

The range of air speeds should be divided into suitable increments, with smaller percentage increments as the high end of the range is approached. For example, the increments for an aircraft having a maximum E.A.S. of 500 knots might be arranged as follows:—150, 200, 250, 300, 350, 375, 400, 410 and then by 10 knot increments to 500 knots. The decision as to what increments shall be used will obviously be influenced by the results of the pre-flight flutter calculations and by the results emerging from the flight measurements as the tests proceed.

The decision as to how many air speed increments to cover in any one particular flight must also be based on similar grounds, but to some extent the decision can be taken by the crew of the aircraft. If the aircraft is instrumented with electronic equipment and carries an observer it is possible to get an indication of the approach to flutter either from a monitoring system, or from some type of pen recorder on which the decay curves can be watched. The approach to a low damping condition can often be detected visibly by the response of the pilot's controls or the aircraft structure, after applying the "jerk." The crew should therefore be instructed not to go beyond certain speeds in each flight and to stop the tests if the damping appears to be falling before reaching the limit set for that flight. To return to the former example, the limiting speeds for each flight might be successively 300, 400, 430, 460, 480, 500 knots, and the increments might be overlapped to repeat the last two records in the preceding flight.

2.5.3. *Procedure of each air speed increment*

Where continuous excitation is being used, the frequency range should be covered as in ground resonance tests at each increment of air speed. It has been found adequate to record at half cycle per second increments but in addition, if visual monitoring is possible, the frequency should be adjusted so that records can be taken on the resonance peaks. If a rapid cut-off of the excitation is possible, a decay curve can be recorded from each resonance peak, so that the damping obtained from the resonance curve can then be checked by the damping obtained from the decay curve. An alternative procedure is

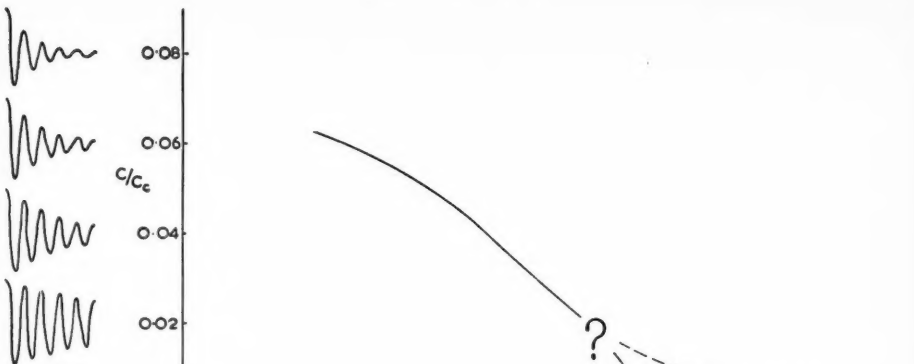

Fig. 15. Hypothetical damping/air speed curve showing approach to critical condition.

to accelerate slowly through the frequency range and to take a continuous recording. From limited experience it appears that the slight saving of time in flight is more than offset by the corrections necessary to the results before the amplitude-frequency curve can be drawn, and the damping values obtained.

When the control jerking method is being used it is suggestesd that two or three jerks of each control should be made at each increment of air speed if the length of recording film permits. There is then a better chance of exciting the potential flutter modes and obtaining satisfactory records.

Figure 14 shows the results of a typical investigation on a Lancaster aircraft fitted with pure servo-tab controls. The incident to which this figure refers was mentioned in Part I, Section 4.

2.6. Safety Considerations

2.6.1. *General*

As in many other aspects of flight testing, the primary requirement for the safe conduct of flutter clearance tests is that there shall be the closest possible co-operation between the crew of the aircraft and all others concerned with the tests. Before starting the tests the crew should be familiar with the general implications of the pre-flight flutter calculations, and as each subsequent flight is made, careful analysis and appreciation of the results is essential before flying through the next air speed increments. The degree of correlation between the flight results and the calculations will give some indication of the reliability of the calculations and if, for example, bad correlation is found, it is advisable to proceed with the flight tests more cautiously. More detailed reference is made to this point later in Section 3.

2.6.2. *Preparation of the aircraft before flight*

It is essential that the friction in the control circuits shall be reduced to a minimum to prevent variations in the response of the aircraft from flight to flight, which would give rise to erratic results or even to a dangerous situation. In this connection the effect of temperature on control circuit friction should be considered when, for example, the flutter clearance tests are combined with a flight to high altitude. The backlash in the controls should be representative of the amount that might be anticipated in subsequent production aircraft.

2.6.3. *Exciting equipment*

It is essential to provide means of stopping the applied excitation rapidly in the event of trouble in flight. When inertia exciters driven by electric motors are being used a rapid stop can be achieved by friction brakes or regenerative braking of the motor, or both. Care should be taken to ensure that impulsive loads, which may arise during rapid braking, are not excessive. If a moving-coil electrodynamic exciter is being used to force oscillations through the control circuit, the coils carrying the alternating current may be disconnected and short-circuited to provide regenerative braking as for the motor.

The exciting equipment should produce forces sufficiently large to overcome any friction in the control surface hinges and to produce amplitudes distinguishable from the normal level of vibration in flight, but at the same time the possibility of damage to the aircraft structure due to fatigue or repeated loadings obviously imposes a maximum permissible amplitude. It is considered that amplitudes at resonance should not in general give rise to alternating stresses in the aircraft structure higher than those arising from the application of ± 10 per cent. of proof load, and, if particularly high mean structural loads occur in any of the flight conditions, it would be advisable to reduce this limit. Some approximate estimate of the maximum amplitudes permitted by this stress limitation could be obtained from theoretical calculations based on the modes obtained in ground resonance tests, but the work involved would generally be prohibitive. The approach used in recent tests is to assume that the fundamental bending mode of the part of the structure of primary concern (*e.g.* wings, tailplane) approximates to the deflection form adopted during normal static strength tests, and to use the tip deflection at 10 per cent. proof loading as a guide to the limiting amplitude in the fundamental bending mode. The excitation applied at higher frequencies is reduced in the degree that experience has shown to be advisable in ground resonance tests. It is fully appreciated that the approach leaves much to be desired and such amplitude would not, in fact, be excited unless it were necessary in order to obtain intelligible records. Rigorous inter-flight inspections are made to detect any signs of structural damage.

2.6.4. *Force applied during control jerking*

No clear-cut guidance can be given as to what force the pilot should apply when jerking the controls. As with continuous forcing it should produce the minimum structural amplitude consistent with adequate results, and the same general precautions apply. One or two preliminary trials by the pilot, starting with small forces at the low end of the air speed range, are usually adequate to establish the order of force required. The problem does not appear to be very real in practice, and the authors know of no case where structural damage has occurred during such tests.

3. CORRELATION OF FLIGHT TEST RESULTS AND PRE-FLIGHT CALCULATIONS

If the damping in a particular mode is seen to be falling seriously during the flight tests, the question arises as to whether it indicates an approach to a critical condition or whether, in fact, the damping will subsequently rise at higher air speeds. This point is illustrated in Fig. 15. Usually, the slope of the damping/air speed curve may give a general indication of the probability of a critical condition arising, but too much reliance cannot be placed on the slope, since it is known that it may change rapidly. The pre-flight calculations which give solutions for the critical condition only are of little help in deciding whether to proceed to higher air speeds, because there is no means of checking their validity from the experimental evidence obtained up to this stage in the tests. The particular value of making pre-flight calculations, which are not solved for the critical condition but for rates of decay in the sub-critical region, becomes apparent in such a situation. The damping/air speed curves obtained experimentally can be compared with the theoretical curves and if reasonable agreement is evident, reliance can be placed on the behaviour of the theoretical curves at higher increments of air speed.

Although the primary aim of the flutter clearance tests is to establish safely whether the aircraft is free from flutter or not, it is obviously desirable from the long-term point of view that experimental results should provide evidence of the validity of the flutter theory. As mentioned in Part I, aircraft controls are designed so that no critical condition should occur over an infinite air

speed range. If this ideal cannot be realised they are designed so that the calculated critical condition will be above the maximum speed of the aircraft. If no critical flight condition is found, in the former case no positive confirmation of the theoretical work can be obtained from the flight tests; in the latter case confirmation can only be obtained by extrapolation of the flight test results beyond the maximum speed of the aircraft. The most that can be expected is that the theoretical work and flight work will then give one extrapolated point for comparison with one theoretical point. If, on the other hand, a critical flutter condition is found within the air speed range, the experimental results may throw little light on the nature of the error in the theoretical work. Again, the value of theoretical calculations solved for rates of decay in the sub-critical region is apparent, as direct correlation of a number of test points with theoretical points within the air speed range is possible.

From the foregoing it will be evident that calculations solved for critical conditions, although invaluable in the design and development stage of an aircraft, are of little help both in the conduct of the flight tests and in subsequent correlation of theoretical and test results. Unfortunately the amount of work required to calculate the damping in the appropriate modes over the air speed range would be prohibitive from the viewpoint of the aircraft designers. However regrettable, such calculations can be justified at present only in relation to long-term research programmes, although the advent of flutter simulators may make damping prediction a reasonable proposition for prototype aircraft in the near future.

4. CONCLUSIONS

On many occasions incidents involving the flutter of aircraft controls have occurred during the flight testing of prototype aircraft. Many such incidents, which are potentially dangerous to the aircraft and crew, might be avoided by a systematic series of flutter clearance tests during the flight test programme. A simple method of making such tests, which requires little instrumentation, is advocated for aircraft having normal, servo-tab or spring-tab controls. In this method the damping of the decay oscillations, resulting from a sharp manual jerk of the controls, is measured at increments of air speed to give warning of the approach to a critical flutter condition. Although the method cannot be guaranteed to prevent all flutter incidents, in the majority of cases warning of the approach to a flutter condition will be obtained and thus the risks of test flying will be reduced.

This simple jerk method of excitation is not satisfactory for aircraft with powered flying controls, and at present it appears that recourse would have to be made to the more laborious methods of continuous forced excitation over the frequency range. The problem of developing a simple method of exciting such control systems is considered to be one of the most outstanding in the field of flight flutter testing.

Apart from the prediction of critical flutter speeds, the methods advocated will reveal any mode in which the damping is low within the air speed range. This knowledge is particularly useful in flutter prediction if changes are to be made to the aircraft controls, or if external stores, which will affect the dynamic and aerodynamic characteristics of the aircraft, are to be fitted.

ACKNOWLEDGMENTS

The authors are indebted to their colleagues at the Royal Aircraft Establishment for their help in the preparation of the paper. Their thanks are also due to the Chief Scientist, Ministry of Supply, for permission to publish the paper.

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PART I

Only a few, of many possible, references are given. The first three are classical works, each covering a great deal of ground; they are not referred to in the text.

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DISCUSSION

Professor A. R. Collar (University of Bristol, *Fellow*): The flutter problem had been studied mostly in Germany, Holland, the United States and Great Britain. But the Continental and the United States approach on the one hand, and the British approach on the other, had been distinctly different. On the Continent and in the United States the tendency had been always to approach the problem from the mathematical end, putting the pure mathematicians on to it; and, at least until recent years, they had avoided the engineering approach via models and had relied very much on theoretical aerodynamics. In Great Britain, beginning with the work of Frazer and Duncan, since in those days there were no theoretical aerodynamics to put in, the problem had been studied by means of models, and from that beginning an engineering approach to the subject had been built up which he believed was unique. It was represented by the existence in this country of mass-balancing rules which were extremely simple, rules relating mass-balance to stiffness, and especially rules in the form of stiffness criteria. It was extremely gratifying to find a lecture on this subject produced in those terms, which he could describe as being in the Pugsley-Roxbee Cox tradition. As the subject had become steadily more complicated it had been more and more necessary to bring in the mathematician, and the temptation to treat the matter from the mathematical end was now considerable. He congratulated the authors, therefore, on having produced a paper in which there was not a single mathematical equation and only one mathematical expression.

One feature which he was glad to see studied in the paper was that of modal forms and the positioning of nodal lines. In the past, that had always been rather a matter of black magic; it had not been well understood and had seldom been set out clearly. To have set it out as it had been in the paper was well worth while.

Another matter in which he was much interested and which he had always regarded as being extremely important was the study of the degree of damping near the flutter boundary. Mr. Broadbent's treatment of it was illuminating. The severity of a flutter occurrence was usually determined by the degree of damping near the boundary: if the rate of change of damping was slight the flutter occurrence was usually quite minor. It was therefore of considerable importance to study, not only the critical condition, but also the conditions near the critical.

Perhaps it would be well to apply a caution in thinking of the single mathematical expression that Mr. Broadbent had shown. It was very rarely indeed that one of the parameters could be altered in the way he had suggested without altering other parameters which did not appear in that expression. He would not wish anyone to think it was easy to alter, for instance, a principal moment of inertia without altering also other coupling terms such as the product of inertia.

In the paper there was a reference to avoiding remote mass-balance weights, and it was a little surprising to note that Mr. Broadbent's attitude to remote mass-balance weights was slightly equivocal. He personally would be completely uncompromising and would say that remote mass-balance weights should be avoided at all costs and at all times, for they nearly always led to trouble. Since it might not always be easy to attach a balance weight directly in front of a control, would Mr. Broadbent comment on the possibility of using the scissors type of mass-balance weight, proposed some years ago by Dr. Frazer. He felt sure that, where it could be applied, this promised to be the most satisfactory type of mass-balance weight; but only very rarely had it been tried, so far as he was aware.

It had been the practice in Great Britain for a long time to ask for a very rigid interconnection between the two halves of

elevators. But, particularly with the coming of the dihedral tailplanes, it had not been possible to adhere closely to that requirement, and he had rather gathered from the paper that the rigid inter-connection was in fact no longer insisted upon. Would Mr. Broadbent enlighten him on the matter ?

Mr. Broadbent had made, he thought, a rather slighting reference to the low efficiency screw jack. He had always felt that with power operation, if they designed the controls reasonably, with appropriate aerodynamic balance—and with a screw jack it did not matter how close the balance or even if there were a slight degree of over-balance —it should be possible to produce a screw jack of low mechanical efficiency which nevertheless would be, aerodynamically, a really efficient irreversible control.

Mr. Kirkby had mentioned the difficulty in flight testing for flutter, of covering the complete range of frequency, equivalent air speed and Mach number. To cover all those, as was obviously the desideratum, in flight tests meant clearly a flight programme the magnitude of which could not be tolerated. It had occurred to him that there might be a way around the difficulty by using, instead of a single frequency, a complete spectrum of frequencies. The existence of such spectra had been known for a long time in connection with turbulent flow and buffeting. In the latter case, a lot of eddies of various frequencies were thrown off from the wing root; the tail sorted out from the spectrum its own natural frequency and by its response, produced the buffeting phenomenon. It seemed to him that considerable time might be saved in flight flutter testing if they could devise an instrument which would put in a whole range of frequencies at the same time —and it should not be beyond the wit of man to produce such an instrument. What were the authors' views on this suggestion ?

Professor A. G. Pugsley (University of Bristol, *Fellow*): He had presented a paper on somewhat similar lines about 15 years ago; it was interesting to look back and consider the changes, and the advances, that had been made.

From the paper the two obvious areas of advance were the resonance test area and the flight test area. Fifteen years ago, resonance tests were only just starting, primarily in connection with wings, and the problem of interpretation was related to wing flutter, and incidentally to aileron mass-balance. Nowadays much attention was paid to the tail surfaces and the elevator mass-balancing problem.

He was very interested to see the way in which particular modes were selected for special study. He was glad to see how reminiscent it was of the early days of resonance testing, but hoped the change of terminology from Kussner's "dangerous" modes to "bad" modes had not come to stay.

In the flight test area there had been a much greater advance. One of the authors had come to Farnborough at about the time when the first flight trials in this country were made which aimed at doing the sort of thing discussed in the paper. The trials were made on a Wellesley at Farnborough to try to discover the changes in the natural frequency of its wings with increasing flight speed and, if possible, the changes in damping. The work was done by J. Shipp. So far as frequency changes were concerned, the results were fairly successful, but for dampings they were inconclusive.

The idea of exciting the wings by air bumps was a natural one; at that time everybody concerned had hated the idea of deliberate mechanical excitation; the view was that they had always to produce an aeroplane which would fly safely through gusts, and so why not make use of them. He felt that that was an argument in favour of applying jerks, and he was glad that the authors favoured that method and hoped to develop it. An obvious development, arising out of the stick jerk method, was to turn to direct mechanical jerking of the wings or ailerons, and he did not see why they should not extend the application of that to machines with or without powered controls.

When using jerks as a method of excitation in flight trials it appeared desirable to minimise control friction, as the authors had said, particularly because friction might delay the onset of flutter so that when flutter came it would be very severe. On this point it appeared that the use of a large, rather than a small, jerk would be the safer from a flutter standpoint; perhaps the authors' could comment on this.

It was indicated in the paper that a method of dealing with powered controls might be through the measurement of impedance and the insertion of that experimentally-determined knowledge into the flutter

calculations. It was also mentioned that a common difficulty might be the non-linearity of the system to be dealt with. Were there measurements showing quite different results, depending on the amplitude of the motion being imposed on the surface ?

H. J. Staite (Chief Research Engineer, Sir W. G. Armstrong Whitworth Aircraft Ltd., *Assoc. Fellow*): He stressed the importance of starting a flutter investigation with the correct basic data. Since the resonance test modes were usually the bases of the calculations, it was imperative that when those were carried out, none of the normal modes was missed. That was not easy when the aircraft was of unconventional design and tests on a similar type did not exist for comparison purposes. Accurate flight test measurements were often seriously delayed because of lack of suitable equipment, and even when such measurements were made they must be viewed with an open mind, since it was possible, for example, to have control surface flutter with the pilot sensing no apparent movement of the control column and the instrumentation yielding no apparent phase relationship between the control and main surface.

In most cases resonance test results were not ready until just before the first flight; in which case, if a particular mode were thought to be bad from a flutter point of view, a speed restriction had to be imposed until the necessary calculations were made. They had come to regard that initial speed restriction nowadays as standard practice; what were the authors' views on the usefulness of a resonance test model, and how simply could a representative model be made in order to overcome some of the present delay in flight testings ?

If the flutter testing of aircraft with powered controls demanded the fitting of such pieces of equipment as inertia exciters, either on the main surface or the control surface, then the initial design must cater for such fitments; otherwise, on a fighter-type of aircraft, with control surfaces becoming thinner and thinner, any installations after flight testing had started would require major modifications.

H. Templeton (Royal Aircraft Establishment, *Assoc. Fellow*): Perhaps there were some aircraft designers who might be wondering what all the fuss was about. They might be thinking, for instance, that 15 years ago they had very good design criteria by which they could mass-balance controls, that they had worked to those criteria and that their aircraft had never fluttered. Now they were told that they must do much more in the way of calculations and flight testing. Why ? He believed the answer was to be found in a careful reading of the paper; but perhaps the authors would not mind if he emphasised the main point, which he believed to be this. When those design criteria were established they had done an extremely good job of work, in that they had stopped the main rot of control surface flutter. Since then they had had very few major disasters in this country from that cause.

But the point with the present position was surely that on two main aspects they must go to rather more trouble. One was that they were building bigger aircraft, which meant bigger control surfaces, which meant bigger mass-balance weights; therefore, if possible, they must economise in the amount of mass-balance weight put in, and must try to determine more exactly just how much mass-balance weight they could get away with.

Secondly—and it must be faced frankly—those early design criteria were only approximate and in some cases might not actually apply, for two main reasons associated with design developments. One was high speed flight. They were now dealing with high speed effects going up towards the speed of sound, where the experience which went into those design criteria no longer applied. The second reason was that of the rather unusual structural forms which aircraft were now taking because of the advance into higher speed flight.

His second point concerned the calculation of non-critical conditions in flutter, *i.e.* the actual damping experienced away from the critical flutter conditions. He thoroughly endorsed the making of such calculations, as giving a more realistic indication of the approach to critical flutter conditions; and Mr. Broadbent's contour diagram was a most revealing picture which told a great deal more than a single curve for critical flutter conditions.

Thirdly, with regard to the aileron " buzz " which Mr. Broadbent had mentioned when speaking of compressibility effects, it had been said that in recent years there had been no real advance in knowledge of the measures to be taken to prevent that phenomenon; and

that was largely true. But one piece of work had been done recently in America, which might be of some interest to those who had not heard of it. The work had consisted of low speed tests on a model, in which the experimenters had simulated what they considered might have been part of the cause of the phenomenon, *i.e.* the breakaway of the boundary layer. They had done that by the simple expedient of putting a little vertical flap normal to the model, which picked itself up out of the surface and went down again, thus causing the boundary layer to break away and re-attach. This had been done over a range of frequencies and they had obtained all the outward and visible signs of compressibility "buzz" without the actual existence of compressibility effects. They had very wisely decided that the experiment did not provide a conclusive answer, but that it was at least an interesting pointer to what might be a major cause.

Mr. Kirkby, in his talk on the flight approach, had not laid too much emphasis on the safety aspect, perhaps rather wisely. In fact, however, the safety aspect had been one of the major bones of contention. Was flight flutter testing safe? He believed that all the people who had considered the problem and who had actually made some attempt at it were reasonably sure that it was a fairly safe technique. This was illustrated by a film received recently at the R.A.E. from America; it was an interesting record in many ways of some actual flight flutter tests on what, frankly, was a very antiquated-looking aeroplane. He believed the actual machine was a Fairchild monoplane, and the tests, which were comparatively recent, were made more or less on the lines that Mr. Kirkby had prognosticated. The experimenters used an inertia exciter in the tail, they had electrical pick-ups to measure the vibrations which they excited over a range of frequencies at increasing air speeds, and they used a rudder mass-balance which was variable in respect of position, so that they could move it towards the trailing edge during flight. They also had a spring device to push it smartly forward of the hinge in case they experienced trouble; but he did not think they had had to use it.

The interesting thing about the tests was that not only did they go right up to the critical flutter condition—and the agreement with theory was displayed in the film in a most sensational way—but they actually went 10-20 m.p.h. above the critical flutter condition and got divergent oscillations. The aircraft was not typical of the modern aeroplane, but it was fairly good evidence that they could look forward to making this sort of test with reasonable safety.

If there were any doubting designers who would like to see the film, the R.A.E. would be only too glad to step up their morale and —to parody John Bunyan in terms of Mr. Broadbent's diagram—help them avoid the Slough of Despond and achieve the Heights of Salvation.

J. Hardman (Sir W. G. Armstrong Whitworth Aircraft Ltd.): Some information had come to hand recently, dealing with experimental flutter results at a particular supersonic Mach number; in comparison with two-dimensional incompressible calculated flutter speeds the results showed a remarkable degree of consistency over a wide range of several parameters. That suggested, with a limited amount of test work, that they could produce empirical curves which could be plotted against sweepback for particular Mach numbers, and then for the designer of the supersonic aeroplane it would be necessary presumably merely to do one flutter calculation at zero Mach number and interpret the results from that.

With regard to spring tab flutter, it would appear that the two-dimensional value of $t_\beta(c_2)$ was not a good approximation to the value obtained in practice. It was known that in a particular calculation that difference caused a considerable change in the flutter boundaries. Was that fault thought to be general and, if so, what was the remedy, since c_2 was a difficult derivative to estimate for comparison at zero frequency parameter?

Dr. H. F. Winny (Fairey Aviation Co. Ltd., *Fellow*): He endorsed Mr. Broadbent's remarks that they should make the necessary flutter calculations at an early stage in design. He had in mind a case of a spring tab where, by saving just a small amount of weight on the tab design, an appreciable amount of weight could be saved on the overall aircraft. With powered controls, if they were seeking irreversibility through them, it was absolutely necessary to do the flutter calculations at an early stage.

In that connection he still felt that the main lack of knowledge was in regard to the aerodynamic characteristics. Perhaps that hardly came within the purview of the paper, but it

seemed to him that the aerodynamic characteristics, especially when they came from the subsonic to the supersonic, presented the main difficulty in the flutter calculations.

There was one point in Mr. Kirkby's part of the paper which he did not understand. Mr. Kirkby seemed to have in mind that, with powered-operated controls, it was not possible to do any experimental work by jerking the controls from the pilot's seat. One would have thought, however, that it should be possible to start an oscillation by jerking the controls. He recalled having spent many interesting, if not frightening, minutes in an aircraft on the ground, jerking the controls, thus producing an oscillation through the power-operated controls; was it not equally possible in flight to jerk the controls and measure the damping on the control surfaces ?

M. O. W. Wolfe (Royal Aircraft Establishment): A point which was becoming perhaps more important now was the necessity to avoid having conditions of low damping such as those to which the authors had referred.

In particular, referring to the authors' curve for tab flutter (Fig. 9 in the paper), the corridor of no flutter between the two branches of the flutter curve was sometimes critically narrow; this gave rise to a condition of very low damping which was obviously undesirable.

There had been one or two instances of trouble with aircraft arising from conditions of low damping of this nature, and it appeared to him that although the elimination of critical flutter within the flight envelope was an indisputable necessity, it might be important also to design aircraft which did not have too low a value of damping in any significant vibration modes.

G. H. Ellis (Vickers-Armstrongs Ltd., Weybridge, *Graduate*): He did not agree with Mr. Broadbent's view that dynamic models were not of much use; he favoured a dynamic model. The time required to complete a vibration mode calculation increased alarmingly as the number of masses went up, whereas with a model, even if a large number of masses were being used, the modes could be obtained fairly quickly.

Further, if somebody asked what happened when a large weight was hung on the aircraft —which the R.A.F. was quite likely to do— one did not want to wait a month in order to get the answer. It was preferable to go down to the shops and hang a weight on a model and obtain the results in an afternoon.

If there were a large number of cases to investigate, such a model would make for cheapness.

Contributed: It had been argued that a model would be inaccurate because the stiffness to be built into the model had to be calculated and that these stiffnesses were quantities which there was much uncertainty about during the early design stages. True, but surely the same stiffnesses had to be used in the mode calculation and therefore any errors in the model results due to inaccurate stiffness calculations would be no greater than the errors in the calculated modes due to the same cause. If, however, a model were produced in which the stiffnesses were easily variable it would be easier to adjust the model and obtain new modes as better stiffness information became available than it would be to repeat the calculations.

W. G. Molyneux (Structures Dept., Royal Aircraft Establishment): It seemed to him that there was a good deal of similarity between measuring damping in the manner indicated by the authors and the measurement of damping in an electrical circuit. The two forms mentioned by the authors were the actual resonance curve and the decay form. The resonance curve method was very similar to the measurement of "Q" in an electrical circuit, and one would imagine that an instrument could be devised to record the damping coefficient directly; one would also imagine that there was enough electronic ingenuity at the R.A.E. to enable them to devise an instrument for measuring damping from the decay form.

MR. BROADBENT

Professor Collar: He was glad to have approval of the discourse in the paper on nodal lines. Every so often a new aeroplane appeared and was resonance tested, and it was necessary to look at the resonance test results and decide whether or not the resonance modes were dangerous. If a wrong decision were made, there was likely to be a flutter incident.

He agreed that, in the mathematical expression that was shown, it was not easy to vary one of the parameters at a time; he was merely trying to show that as parameters

they were related to some extent, and the results from the variation of one could be used to predict the effect of variation in another.

Although Professor Collar seemed to think that he was compromising in what he had said about remote mass-balancing in the paper, he agreed heartily that it was a bad thing; from his point of view, the more mass-balances that were directly connected to their control surface, the better, for thereby a lot of trouble was avoided. But he believed that in certain cases the advantages of the remote mass-balance might just about make it worth trying. If concentrated mass-balances were to be used in the tail unit, he agreed that the scissors type of mass-balance was least likely to cause trouble, but it was only practical for weights placed in the fuselage. This scheme placed the weight behind the hinge line rather than forward of it, thus keeping it near to the masses it was balancing and less likely to be in trouble from a dangerous resonance mode.

The only case where he would like the inter-connection of the two halves of the elevator done away with was that of spring tab designs. From the flutter aspect the best arrangement was to have one tab on each side of the elevator, with no direct connection at all, the circuit going separately to each tab.

The authors were not thinking of the application of screw jacks except in connection with powered controls. He could not see any reason why a low efficiency screw jack, operated manually, on a closely balanced aerodynamic surface should be impracticable; and that scheme had been put into practice on one aircraft on a servo-tab. The tab was closely aerodynamically balanced and was operated directly by the pilot through a screw jack. With powered controls the excessive friction on the output side of the power unit might lead to mechanical difficulties.

Professor Pugsley: He agreed that they had not progressed very far in the business of interpreting resonance tests since Professor Pugsley had dealt with this subject at the R.A.E.

Profesor Pugsley was right in regard to the non-linearity of power controls, and their measurements did show different results according to whether a large or a small exciting force was used. But he believed that although little experimental evidence was available in most cases which had been tested the lower impedances were given with the small excitation forces; that was perhaps an argument against the use of a powerful jerk.

Mr. Staite: All would agree on the extreme importance of ensuring that none of the modes was missed in the ground resonance tests.

He did not see a great deal of point in the type of strip model that was used on some occasions. In order to produce that model they had to calculate the aircraft stiffnesses and build the strip to give the right reproduction of them and if they were to calculate aircraft stiffness they might as well go on and calculate the aircraft modes of vibration themselves. A difficulty which applied to all resonance models was that if they were built early in the development of the aircraft, by the time the aircraft was built it had taken up a totally different shape from what was originally intended, and the models were out-of-date. The advantage of such a model, however, was that rapid variations of inertias, and so on, could be made to see the effect on the modes.

In certain cases they had had to deal with an aircraft for which it was difficult to calculate the normal modes, and they had come to the idea of scaling down the aircraft rather more exactly than was the case in simple strip representation. That had given very good results in one case at any rate. There was the same difficulty, however, about modifications of the aircraft delaying the model so that one might not get the results much before the aircraft was ready to be tested, and by then, of course, it was too late.

Mr. Templeton: He agreed with all Mr. Templeton had said about the purpose of the paper, and on the point that the design criteria had done noble service in the past. He was also very interested in the remarks on compressibility effects at aileron surfaces.

Mr. Hardman: On control surface flutter the number of parameters would be very large, and would involve a great deal of testing work.

All the derivatives were liable to be very important, and particularly some of the obscure ones, such as the cross-dampings. It was common practice to correct the two-dimensional flutter derivatives by factors based on the static estimates.

Dr. Winny and **Mr. Wolfe:** He agreed with Dr. Winny's remarks, and with Mr. Wolfe's emphasis on the importance of eliminating the condition of low damping. The corridor between the branches of the curve for spring tab flutter was a perpetual source of trouble; and in the paper it was stated that servo tabs made it easier than did spring tabs to get a wider corridor. He was not clear on their relative merits from the aerodynamic point of view.

Mr. Ellis: Mr. Ellis wanted to build a dynamic model, and seemed to have the right reason for building it. Perhaps he had spoken a little too strongly when he had said that he did not see much point in that type of model; purely as a time saver it might be well worth while. But they should beware of expecting to obtain more accurate results from such a model than from calculation.

The inaccuracy of the stiffness calculations referred to, was an intrinsic inaccuracy; the point about changes in design was covered separately. That meant that neither the model nor calculation would predict full-scale accurately. He was not trying to argue that calculations would give better results than a model, but to point out that a model would not normally give much better results than calculation, as was sometimes expected of it.

MR. KIRKBY

Professor Collar: He agreed that some method of covering more quickly and adequately the frequency air speed and Mach number variables would be most desirable. They had cut down very drastically indeed on what they would like to do. To a large extent it was a matter of what the aircraft manufacturer was prepared to do in order to carry out flutter clearance tests; but he looked forward to arriving at a means of shortening the test programme.

If they could find something better than the manual method of applying the jerk, if they could perhaps apply a saw tooth force-time function—he believed it contained all the harmonics—they would expect to be able to excite the maiority of the modes.

With powered controls, where the jerk method was not satisfactory and the aircraft manufacturer might feel that continuous excitation equipment was too complicated, it was suggested in the paper that the aircraft should be flown through some bumpy weather and that, after hitting the more vigorous bumps, records should be taken.

Professor Pugsley: They were not very happy about using "bumps" because they did not know what force/time function had been applied, but if the function could be measured one could obtain a better idea of the reliability of the results.

He did not see immediately how very large jerks could be applied without giving rise to very high local stress concentrations; he felt that it required quite a lot of thought.

Mr. Staite: He sympathised about the lack of equipment for flutter testing aircraft.

It had been said that sometimes there was no apparent phase relationship between the control surface and the main surface; this difficulty might have arisen due to lack of equipment and consequent effort to measure wing and aileron motion with three linear pick-ups only—on the wing leading edge, wing rear spar and aileron trailing edge. If they could use separate pick-ups to measure rotation of the aileron, for example, they could amplify the output from those pick-ups to a great extent and probably get more accurate phasing.

He agreed that it was an appalling thought that they might have to put inertia exciters in thin control surfaces. There were some American tests on fairly small aircraft in which inertia exciters were used in the control surfaces; but the work had really emphasised the need for a better method of testing.

Dr. Winny: Perhaps the instability he had experienced was a "servo-loop" instability of the powered control unit as distinct from flutter instability. As an example of the latter there was the case of flutter of a control surface due to the flexibility of its linkage to an "irreversible" jack; in that case it was necessary to apply the jerk or oscillation at the control surface end of the system.

Mr. Molyneux: He agreed that an instrument for measuring damping directly would be extremely valuable; he would talk to the electronics experts about it.

Graphical Analysis of Trans-Canada Airlines' Progress on the North American Routes 1946 - 1950

ADAM JAWORSKI, Dr.(Ivr.), M.Sc.(Eng.), M.E.I.C.

INTRODUCTION

Progress of any organisation may be related either to an assumed basis within the organisation itself, or to some other organisations, preferably competitors in the same business. The second method is more realistic and by relating the corresponding data in ratios, it helps to eliminate to a great extent the influence of price changes, which distort yearly comparisons of revenues and expenses.

In the United States the trunk lines represent over 95 per cent. of the total revenue ton-miles flown on the domestic routes and in international aviation, the largest system with the highest quality of service. Therefore, by comparing in Part I the domestic services of Trans-Canada Air Lines (T.C.A.) to corresponding services of the U.S. trunk lines, the most severe criterion was chosen.

Part II contains an investigation of trends of particular expenses in relation to the total expenses for T.C.A's North American Services.

There is no single index by which an airline's efficiency can be assessed. The changes from year to year of expenses per unit of service are not only the function of efficiency, but also reflect the general fluctuations of prices. Even the changes in a physical index, like weight load factor, will alter its bearing on costs, when the size of fleet has undergone change too.

The main object of the analysis of T.C.A's figures expressed as percentages of trunk lines data, is to indicate the trends and rates of change but not to discuss the absolute values of the ratios.

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Mr. Jaworski is with the Air Transport Board, Ottawa, but the views expressed in the paper are his own, and do not necessarily represent those of the Board.

If not otherwise stated, any reference to progress in Part I implies the progress of T.C.A. relative to the trunk lines.

In all graphs a semi-logarithmic scale has been used for the following reasons:—

Logarithms—as distinct from ordinary scales—illustrate the rate of change, and not the absolute values of changes. Both these characteristics are useful in the present analysis. Dynamics of the economical trends are better presented by the rate of changes than by the changes only.*

No direct assessment could be made from a logarithmic graph in respect of the differences in absolute values. This is a good precaution against erroneous conclusions from figures presented in Part II, where particular expenses are expressed as percentage of the total expense. Thus absolute differences cannot be calculated between the percentage data of different years, because the total expense changes from one year to another. The logarithmic method eliminates the temptation of computing absolute differences.

An analysis† published by the author illustrates the correlation between the revenue passenger miles flown by T.C.A. on the North American routes and such factors as frequency of schedules, block speed, safety and fares.

*Logarithm scales are now more frequently used in economic studies than before, *e.g.*, *Economic Survey of Europe, 1950*, by the United Nations Department of Economic Affairs, where semi-logarithmic graphs are used for illustrating the index of prices, production, and cost of living. When to an index, *i.e.*, a ratio, the logarithmic scale is applied, analogous to mechanics, the line on the graph will illustrate an acceleration of the process.

†The Statistical Analysis of Trans-Canada Air Lines, *Aircraft Engineering*, Vol. XXII, No. 255, May 1950.

PART I*

A COMPARISON WITH THE UNITED STATES TRUNK LINES

SUMMARY

T.C.A. has been compared with the U.S. trunk lines with respect to traffic and income on North American services during the period 1946-1950. By taking the U.S. trunk lines totals as 100, the analysis disclosed the following major points:—

(*a*) T.C.A's total revenue ton-miles rose from 2.57 per cent. in 1946 to 4.59 per cent. in 1950.

(*b*) Revenue ton-miles per unit of fuel consumed increased from 73.4 per cent. to 97.5 per cent. during the period under review. This ratio constitutes a good index of fleet efficiency.

(*c*) Revenue ton-miles per dollar of salaries and wages rose from 55.4 per cent. in 1946 to 99.1 per cent. in 1948. The ratio might be termed a personnel efficiency index. This ratio showed the highest relative rate of increase of all the factors examined, during the period 1946-1948.

(*d*) Air mail revenue per ton-mile of mail carried showed the highest rate of decrease of all factors examined during the period.

(*e*) T.C.A. total revenues less air mail revenues rose from 2.81 per cent. in 1946 to 3.51 per cent. in 1950. The deduction of payments for carrying air mail eliminates the controversial matter of mail revenues.

(*f*) T.C.A. total expenses during the period advanced from 4.04 per cent. to 6.22 per cent.

(*g*) In 1950 T.C.A. had improved its relative position in the national economy by 72 per cent. compared with 1946. The corresponding figure for the trunk lines is 28 per cent. T.C.A. Domestic Services in 1950 had a better relative position in the national economy than the trunk lines. In 1946 the reverse was true.

Although T.C.A's total income had improved considerably in 1950, the U.S. trunk lines showed greater gains, so that T.C.A's relative position deteriorated slightly in relation to 1949 only.

It would be rash to look for a reversal of the favourable trends shown by T.C.A. in relation to the U.S. trunk lines, during 1946-1949. The replacement of the U.S. trunk line fleets with larger aircraft which will receive extensive use as a result of the direct and indirect impact of defence preparations, will make relative progress for T.C.A. more difficult in the future. T.C.A's further progress relatively to the trunk lines is not provable, although it is probable.

*Only a summary of Part I is given here. The full text, which may be of some interest to readers in the United States, will be published shortly by the *Journal of Air Law and Commerce*, which is issued by North Western University.—AUTHOR.

PART II

TRENDS OF PARTICULAR EXPENSES

SUMMARY

An attempt has been made to develop a "yardstick" for the determination of the trend of an airline's expense accounts.

Using the figures presented in the Annual Reports of Trans-Canada Airlines for the period 1946-1950, a method has been developed whereby the trends of individual items of expense may be determined. Comparisons of the trends of individual items with the trend of overall revenue and expense indicate those items which show abnormally unfavourable behaviour and which therefore should be closely investigated.

Engine maintenance cost, especially material cost, shows a remarkable upward trend, if expressed as a percentage of total expenses less depreciation. The average rate of increase of that ratio during the period 1946-1950 is even faster than that of traffic measured in available seat-miles. With respect to rate of increase, the expense ratio of engine material is followed by the ratios of engine labour, aircraft material and labour, in that order. The average rate of increase for fuel and oil is much smaller.

Of the expense ratios with a decreasing trend, the most significant is the Passenger Service account, followed by the Pilots Expense (Captains' and First Officers' salaries).

1. INTRODUCTION

It was desired to develop a method for revealing the trends of individual expenses of an airline to permit an intelligent appraisal of

the financial progress of the airline, and to indicate where effort should be directed.

To provide financial data it was decided to use the North American services of Trans-Canada Airlines as an example. All information was obtained from the annual reports of T.C.A. for the years 1946-1950 inclusive. Figures for any year before 1946 had no comparative value.

Since the expenses of an airline are related to the type of aircraft used in the fleet, the figures for T.C.A. operations during 1951 will be required before the effect on the various trends of introduction of North Star aircraft in June, 1948, becomes clearly evident.

2. The number of expense accounts

In the T.C.A. annual report for 1950, the expenses are shown in 10 groups and 166 different accounts. In the present analysis only groups of separate accounts where the expense in 1950 was over $0.5 million (1.6 per cent. of the total expense) have been considered. Therefore, the number of accounts investigated is restricted to 15, which when combined represent 88 per cent. of the total expense. If the splitting is carried far enough, even an account representing one per cent. of the total is relatively important because there will be many accounts which differ only by a decimal from one per cent.

3. The real value of expense

The Wholesale Price Index in Canada during 1946-1950 shows the following changes*:—

1946	138.9
1947	163.3
1948	193.4
1949	198.3
1950	211.2
(1935-39 =	100)

Therefore, some of the T.C.A. expenses during this period may show a 50 per cent. increase irrespective of changes in traffic, and usually the increasing trend must be attributed both to increases in prices and in traffic. The simplest method for correction of price influence is to use the Wholesale Price Index, but the appropriate price index for T.C.A. may only by coincidence be the same as the average for the whole country. J. H. Payne's index† for the American Airlines (containing items representing 75-80 per cent. of the total expense) shows an increase of 8.1 per cent. for 1949 over 1948, when the Wholesale Price Index in Canada underwent an increase of only 2.5 per cent. for the same period.

In the U.S.A. the Interstate Commerce Commission (I.C.C.) in an analysis of railway expenses, has introduced a separate correction index for different accounting groups. In the report published in 1948, 23 indices have been used to correct changes in prices and wages*. Some of them are simple, like fuel price in the fuel account, but a group such as maintenance accounts must have a combined index to reflect fluctuations of material prices and labour costs. For the total expense the correction index is a weighted average of indices from all accounting groups. The refinement for time lag made by the American railways may be illustrated by so-called charge-out price levels. They are commonly calculated for a given year by averaging the price indices as of the previous December and the current June. This is because of the time lag between the dates on which supplies are purchased, and the dates on which they are used and charged to operating expenses†.

In this analysis it is desired to stress the trend in ratio of revenues and expenses. Therefore the total expense minus depreciation account may be used as a common denominator. The deduction of depreciation charges from the total underlines in the remainder, *i.e.* the reference base, variations due to changes in prices and traffic. Depreciation, according to the accounting procedure, is related to the first price of equipment, but such procedure during an upward trend of prices undermines the chief economical object of depreciation; to safeguard the capital investment, and although the book value is unchanged, the real value of the investment is sinking as much as prices are rising.

Depreciation, especially in the air transport industry, should not be mixed up with the replacement cost, because the old aircraft are mostly replaced with a superior type that

**Canadian Statistical Review*, May 1951.
†*American Aviation*, 27th Nov. 1950, p. 18.

*I.C.C. (Bureau of Accounts and Cost Findings): Explanation of Rail Cost Finding Procedures and Principles Relating to Use of Costs, Washington, D.C., Oct. 1948, p. 228.

†Association of American Railroads, Bureau of Railway Economics: A Review of Railway Operations in 1947. Special Series No. 77, Washington, D.C., 1948.

costs more, but has a higher working capacity. Thus fewer aeroplanes will be needed for the same job with a reduced cost per available seat-miles, even when the introduction cost into scheduled operations is accounted for.

4. Measurement of particular expenses

Probably a justified comparison of expenses could only be made by introducing basic physical units such as man-hours, gallons, etc. It is interesting to notice that even some engine manufacturers consider the miles flown as a better criterion for aircraft maintenance than engine hours*. For a fleet with unchanged seat capacity and block speed, the changes in seat-miles and hours flown will be equal.

The denominator "total expenses less depreciation" includes two factors: one which reflects changes in prices, and one which varies in the same sense as the traffic. Therefore, ratios using such a denominator as a function of traffic (measured in available seat-miles), will indicate a real value of a particular expense or revenue, but the increase with traffic is higher than actually shown by the ratio because the denominator is also growing with traffic.

In any airline which experiences an increase in traffic, *e.g.* T.C.A. in 1946-1950, the total expense must have an upward trend. Therefore, when a particular expense shows a constant ratio from year to year, the absolute figure of this expense will show an increase. Moreover, a slightly decreasing ratio of an expense may occur together with an absolute rise of this expense, when the total expenses rise sharply.

To discover the particular expenses which grow much faster than the total, the ratio method is also useful when the traffic is curtailed with a view to reducing the total expenses. The most "stubborn" expenses will still be indicated by a rising ratio although their absolute values may decrease, but on a slower scale than the total expense.

It is interesting to determine how an increase of a single expense changes the ratio of other expenses to the total expense.

For an airline using the C.A.B. accounting system, which was adopted by T.C.A., the greatest single account is fuel consumed, which for T.C.A. is roughly 16 per cent. of the total expenses less depreciation. Assuming that this expense has increased by one third with other expenses unchanged, any other expense account of an order of, say, 15 per cent. of the total, will be changed to 14.2 per cent.

Even with such an unlikely assumption that the most important account has increased by one third and that the other accounts remain unchanged, the maximum influence on the other accounts will be less than 5.5 per cent.

5. Unit of traffic measurement

According to T.C.A's annual reports, the revenues from passenger transportation in the North American services, during the period investigated, indicates a steady increase in percentage of the total:—

Year	1946	1947	1948	1948	1950
Passenger revenue as percentage of the total revenue	62.8	68.3	71.3	73.4	76.0

Therefore T.C.A's North American Services are predominantly of a passenger nature and an appropriate unit for traffic measurement in a general analysis of revenues and expenses must therefore stress the passenger character of traffic. It seems that available seat-miles fulfils the requirement as a unit of traffic, especially with respect to expenses and potential passenger revenues.

The available seat-miles during the period investigated were as follows:—

Year	*Average seat miles flown*	
1946	204,967,648	100.0
1947	288,503,511	140.8
1948	367,455,955	179.3
1949	459,842,123	224.3
1950	548,850,808	267.8

It may be seen that the yearly increment of increase in traffic (expressed in available seat-miles) between 1946 and 1950 is almost constant and equals approximately 40 per cent. of the 1946 value. Consequently, the graphs which are related to such a traffic unit will not be affected appreciably if, for this traffic unit, a pure time unit of one year is substituted.

*Lord Hives: "It is submitted that mileage is the logical basis for aircraft and general maintenance periods and not hours" (*Journal of the Royal Aeronautical Society*, Feb. 1945, p. 69).

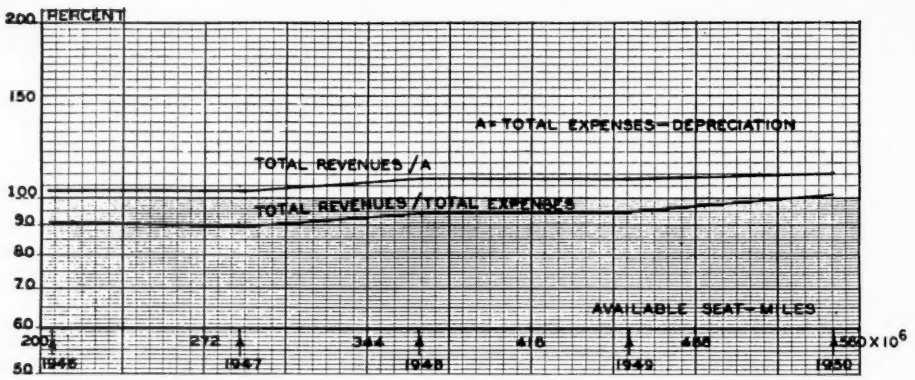

Fig. 1. T.C.A. North American Services (1946-1950): Ratio of total revenues and expenses.

Although the available ton-mile incorporates air cargo as well as passengers, it is assumed that for one available ton-mile there is equality of revenues from passenger and air cargo and also equality of expenses in both services. Such an assumption is very unrealistic, especially for costs, which are much higher on a weight basis for passenger service than for air cargo.

Probably gross-ton-miles are a better cost unit than available ton-miles, because they reflect aircraft characteristics. (When two fleets, one of them using larger aircraft, are producing the same available ton-miles, the costs for the fleet with a smaller aircraft will be higher.)

6. Warning Signals. General

When an airline has shown a deficit for several years it is important that there should be an increasing trend in the ratio total revenues/total expenses, otherwise there is no hope at all of emerging from the "red." However, it must not be overlooked that when expenses are growing fast with rising traffic, a slight improvement in the trend may be accompanied by an increase in the absolute figures of deficit.

7. Total Expense as a Ratio of Total Revenue

The general relation of revenues to expenses is illustrated by Fig. 1. The curves of total revenues as a ratio of total expenses, and total expenses less depreciation, have a very similar pattern. The decrease of the latter ratio in 1949 is explained by the decrease in relative importance of depreciation compared with total expenses in 1949.

By a drastic reduction of specific expenses, it is possible to reduce the deficit considerably in spite of a decrease in revenues. The B.E.A. deficit in 1949-1950 was cut by 51 per cent. because the specific cost of a capacity ton-mile flown fell by 26.5 per cent., but the specific revenue shows a decrease of only 6.05 per cent. (77 per cent. of the revenues in 1949-1950 came from passenger fares.) The development of air-cargo could also be used as a remedy for cutting losses*.

When a new type of aircraft is introduced into service, for reasons of economy (*e.g.* in fuel consumption) the average consumption after the introduction is lower, *i.e.* the expense of fuel ratio versus traffic would demonstrate a slower rate increase.

8. Expense Ratio of Aircraft Engine Material

From 1947 onwards this item shows the sharpest increase of all in this analysis. It even surpasses by a large margin the rate of growth of traffic (Fig. 2).

*The development of air cargo in 1949-1950 by Aer Lingus was chiefly responsible for reduction of its loss by *nine-tenths*. This was a remedy for strong seasonal variations in passenger transportation (*The Aeroplane*, 25th August 1950, p. 225).

The latest domestic traffic forecast in the United States has again new hopes for cargo; almost a five times higher increase during the next 30 years than the passenger-miles. (Air Traffic Forecast 1950-1980, published by the Port of New York Authority, Department of Airport Development, Airport Planning Bureau, June 1950, pp. 18 and 45.)

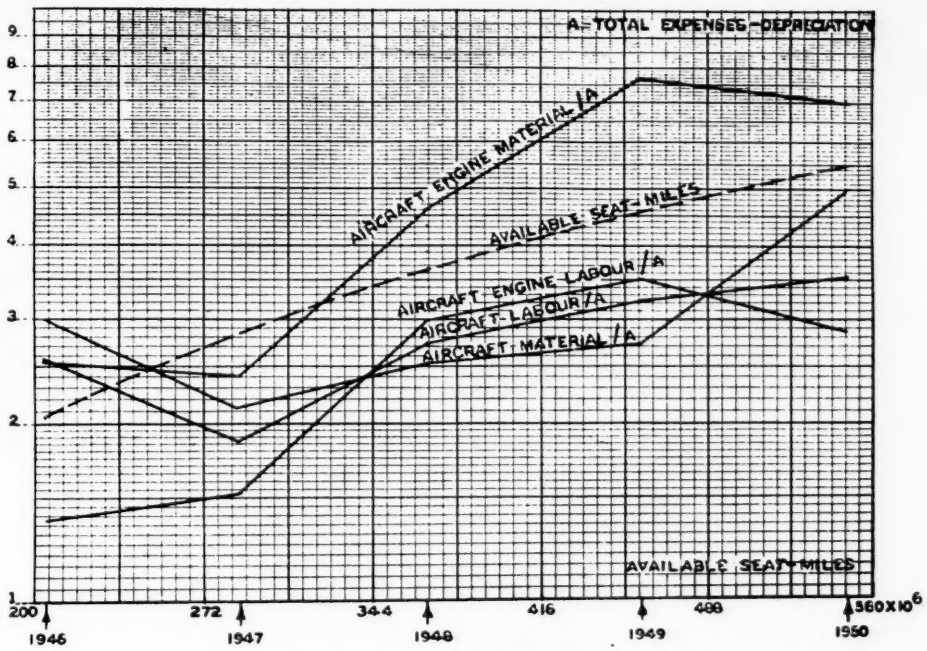

Fig. 2. T.C.A. North American Services (1946-1950): Ratios of particular expenses and total expense less depreciation.

This must also be reflected in a shifting of its relative importance. It may be noticed that the Aircraft Engine Material which in 1946 represented only 2.5 per cent. of the total expenses less depreciation, rose in 1949 to 7.7 per cent. Fortunately, in 1950, the rate of increase of this account was checked, and its percentage dropped to 7.03. But the increase of the Aircraft Material account in 1950 has wiped out this gain. (The combined expense of material and labour for the aircraft and engines in 1949 represents 17.16 per cent. of the total expenses less depreciation, compared with 18.50 per cent. in 1950.)

9. Expense Ratio of Aircraft Engine Labour

This is connected with the Aircraft Engine Material item because the replacement of engine parts, besides the cost of material, must also bear labour expense. Therefore, the ratio of Aircraft Engine Labour, as a result of its sharp increase, takes the next place after Aircraft Engine Material. The shifting of the relative importance was from 1.4 per cent. in 1946 to 3.5 per cent. in 1949, but the rate of decline in 1950 was even greater than for the Engine Material (Fig. 2). In order of absolute value this expense is less than twice the amount of Aircraft Engine Material.

10. Expense Ratio of Aircraft Labour

After reaching its lowest point of 1.87 per cent. in 1947, this indicates a conspicuous growth, rising to 3.56 per cent. in 1950 (Fig. 2).

11. Expense Ratio of Aircraft Material

This item, connected with Aircraft Labour, showed an almost equal rate of decline in 1947. Its subsequent rise is on rather a slower scale, but in 1950 the rate of increase significantly surpasses the aircraft labour expense (Fig. 2).

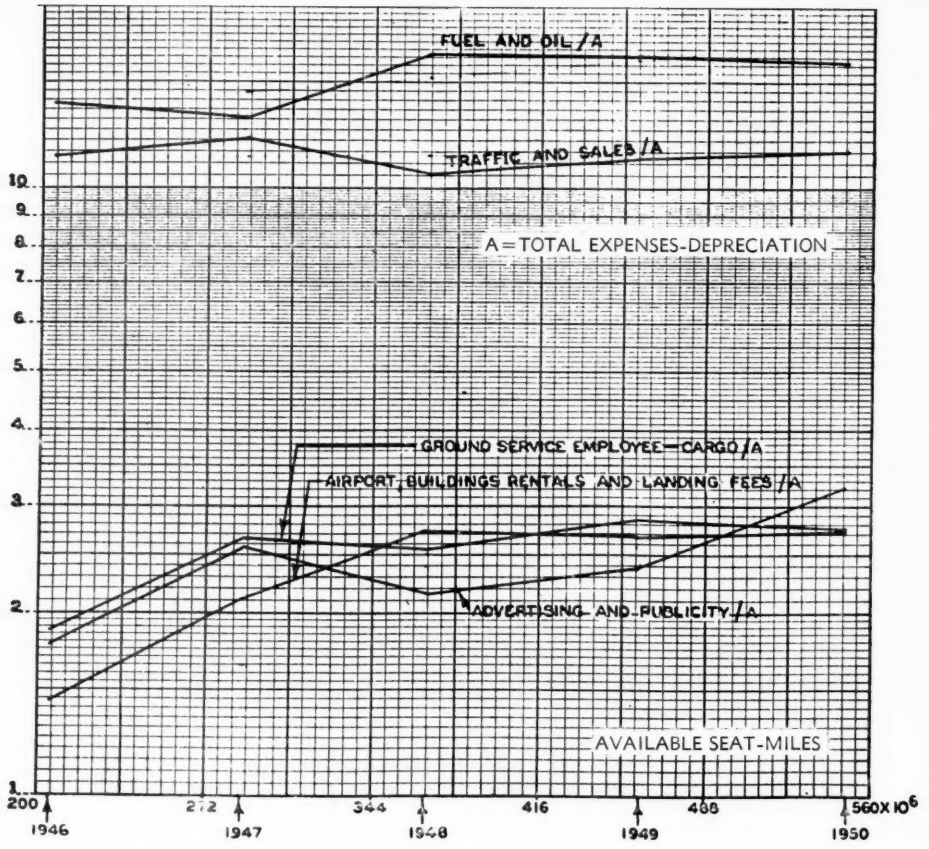

Fig. 3. T.C.A. North American Services (1946-1950): Ratios of particular expenses and total expense less depreciation.

12. EXPENSE RATIO OF AIRCRAFT ENGINE FUEL AND OIL

This shows a sharp rise between 1947 and 1948, corresponding almost exactly to the traffic increase. From 1948 the ratio is practically constant, which is a good sign, because fuel cost is directly connected with traffic, which increases much faster (Fig. 3).

13. EXPENSE RATIO OF TRAFFIC AND SALES

With some ups and downs this ratio in 1950 is practically on the same level as in 1946 (approximately 11.5 per cent. of the total expense less depreciation) (Fig. 3).

14. EXPENSE RATIO OF ADVERTISING AND PUBLICITY

This has an upward trend, but with a zig-zag pattern. It will be interesting to see whether the revenues in 1951 will justify the sharp rise in 1950 (Fig. 3).

15. EXPENSE RATIO OF GROUND SERVICE EMPLOYEES—CARGO

The general trend shows a marked rise, reaching 2.8 per cent. in 1950, from 1.9 per cent. in 1946 (Fig. 3).

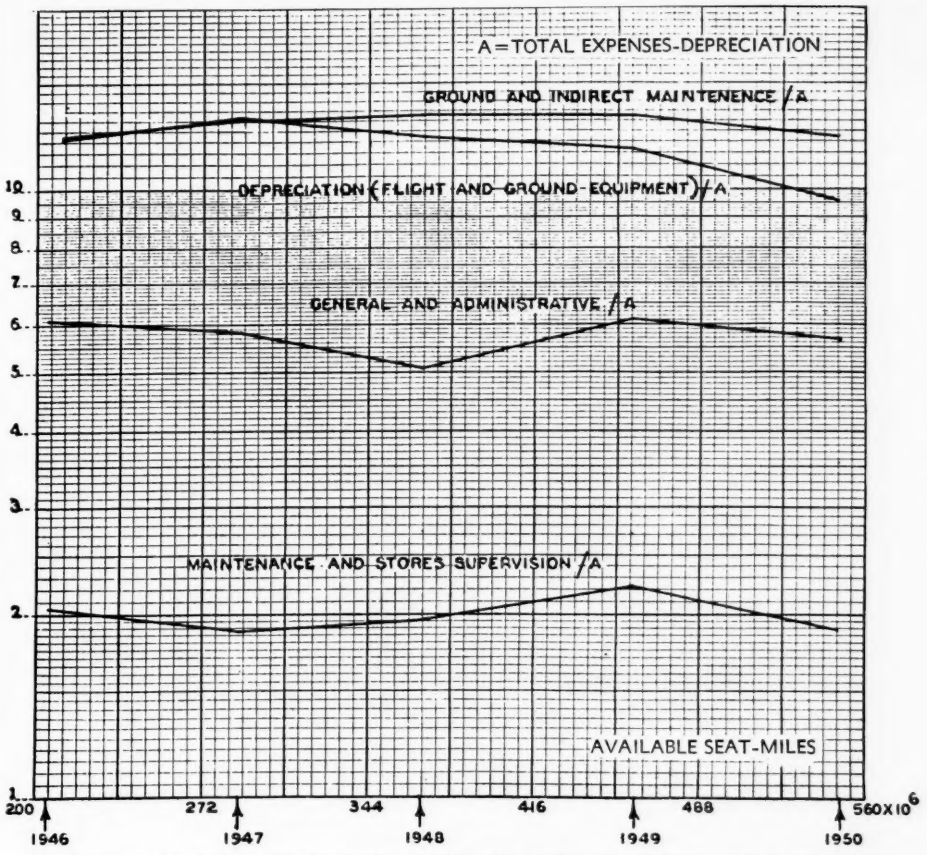

Fig. 4. T.C.A. North American Services (1946-1950): Ratios of particular expenses and total expense less depreciation.

16. EXPENSE RATIO OF AIRPORT, BUILDING, OFFICE RENTALS AND LANDING FEES

This has a similar pattern to the previous expense. Unfortunately landing fees are not separately shown in the Annual Report for 1946 (Fig. 3).

17. EXPENSE RATIO OF GROUND AND INDIRECT MAINTENANCE

This is practically constant, being 12.2 per cent. in 1946 and 12.3 per cent. in 1950 (Fig. 4).

18. EXPENSE RATIO OF DEPRECIATION

After an increase in 1947 the rate of depreciation indicates a steady drop in relative importance, reaching 9.5 per cent. in 1950 against 12.2 per cent. in 1946 (Fig. 4).

19. EXPENSE RATIO OF GENERAL AND ADMINISTRATIVE COSTS

After a temporary decrease in 1948, this is practically on the same level in 1950 as in 1946 (Fig. 4).

20. EXPENSE RATIO OF MAINTENANCE AND STORES SUPERVISION

This is a component of the Ground and Indirect Maintenance account previously discussed (Section 17), with fluctuations, but the trend is identical, *i.e.* practically a constant ratio (Fig. 4).

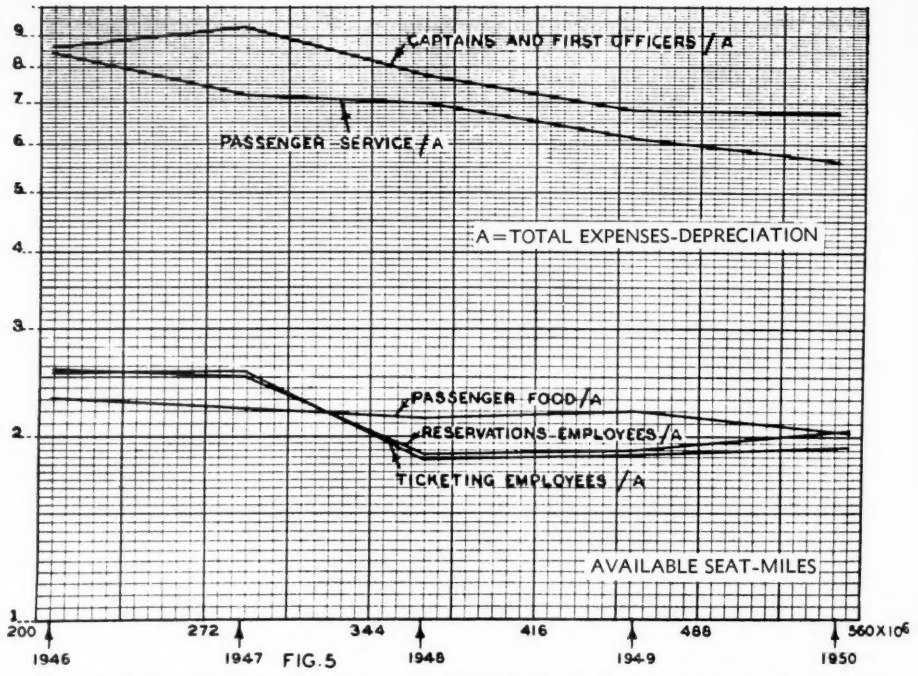

Fig. 5. T.C.A. North American Services (1946-1950): Ratios of particular expenses and total expense less depreciation.

21. Expense Ratio of Captains and First Officers

The downward trend was broken by a temporary rise in 1947 (Fig. 5).

22. Expense Ratio of Passenger Service

A similar downward trend as the previous ratio but without a rise in 1947 (Fig. 5).

23. Expense Ratio of Reservation and Ticketing Employees

Both these are components of the traffic and sales expense discussed previously (Section 13), each representing about 17 per cent. of that expense and 2 per cent. of the total expenses less depreciation. A pronounced downward trend in rate of change of both can be noted, as in the whole group of Traffic and Sales expense (Fig. 5).

24. The Average Rate of Increase or Decrease of Particular Expense Ratios

During the period 1946-1950 each expense previously discussed, when related to the total expense less depreciation, shows on the semi-logarithmic graph a different average rate of change. However, for the following four expenses, the rate of change during that period did not show any significant trend (upward or downward):—

General Administration
Ground and Indirect Maintenance
Maintenance and Stores Supervision
Traffic and Sales.

If the ratios of expenses are placed in order of rank, starting with the maximum rate of increase or decrease, including the rate of traffic increase (expressed in available seat-miles) and a ratio of total revenues and expenses, the general summary in Table I may be presented.

TABLE I

RANK OF THE AVERAGE RATE OF CHANGE OF T.C.A. DOMESTIC TRAFFIC EXPENSE ACCOUNTS AND TOTAL REVENUES RELATED TO TOTAL EXPENSE LESS DEPRECIATION

(1946-1950)

(*See* Figs. 1-5)

Rank of change	*Ratios of expenses and revenues with an increasing rate of change*	*Ratios of expenses with a decreasing rate of change*
1	Aircraft engine material	Passenger service
2	Traffic (available seat-miles)	Captains and First Officers
3	Aircraft engine labour	Ticketing employees
4	Aircraft material	Reservations employees
5	Aircraft labour	Depreciation
6	Airport building and landing fees	Passenger food
7	Advertising and publicity	
8	Ground service employees—cargo	
9	Aircraft engine fuel and oil	
10	Ratio of total revenues and total expenses	
11	Ratio of total revenues and total expenses less depreciation	

It was stated previously that the particular expenses have a higher rate of increase or decrease with the traffic increase than that indicated by their ratio, because the common denominator, *i.e.* total expense less depreciation is rising with traffic.

All expenses whose ratios are increasing faster than the ratio of total revenues and expenses should be investigated carefully, especially if the rank of the rate of increase is close to the rate of traffic increase.

ACKOWLEDGMENT

The author is grateful to Mr. J. C. Finlayson, former Acting Chief of the Research Aeronautical Engineering Branch, Air Transport Board, for reading the draft of this paper and for making valuable corrections.

REFERENCES

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2. C.A.B., Annual Airline Statistics, United States Certificated Air Carriers Calendar Year, 1946-1948.
3. House of Commons 1950, Sessional Committee on Railways and Shipping, Minutes of Proceedings and Evidence.
4. National Accounts, Income and Expenditure, Preliminary 1950, Dominion Bureau of Statistics, Ottawa.
5. Survey of Current Business, July 1950 and February 1951, U.S. Dept. of Commerce, Washington, D.C.
6. T.C.A. Annual Reports for 1946-1950.
7. *World Airline Record*, 1950-1951, published by Ray R. Roadcap, Chicago, 1950, Mil. op. etc.

New Zealand Division

THIRD ANNUAL REPORT: FOR YEAR ENDED 31st DECEMBER 1951

THE year has shown steady progress throughout the four Branches. Although the increase in membership has not been large, nevertheless the activities of each Branch have been extended and consolidated. It may be fairly claimed that the Society has now been firmly established in New Zealand and that steady progress and satisfactory public support will follow.

During the year the Council prepared draft rules for the operation of the Division. These rules are now being examined by the Society and in due course will be submitted to members of the Division for approval. Rules for the four Branches, which are substantially identical, have been approved during the year by the Council.

This year New Zealand had the honour of supplying the paper for the Seventh British Commonwealth and Empire Lecture. This paper was " Air Transport in New Zealand and the South Pacific " by Air Vice Marshal Sir Leonard Isitt, K.B.E. It is also pleasing to be able to report that a paper submitted by a local member, Dr. Marshall Laird, M.Sc., Ph.D., Companion R.Ae.S., has been published in the JOURNAL (November 1951).

The Council has prepared draft conditions for an award to be known as the Henry Wigram Memorial Lecture which are now submitted for approval of members. The objects of establishing this lecture are to commemorate the memory of the foremost pioneer in the development of aviation in New Zealand, and likewise to promote the aims of the Society. It is proposed that the paper should make an original contribution to aviation knowledge in New Zealand, in a subject of a scientific, technical, economic or operational research nature connected with aviation activities in New Zealand or the South Pacific.

The Council has taken an active part in sponsoring and organising an Aviation Industries dinner which is to be held in the middle of the year. This function, which will be attended by a number of Parliamentary guests, will be representative of all sections of the industry throughout New Zealand. The objects of the gathering are to bring together for the first time the diverse elements associated with the growth of aviation in New Zealand, and to emphasise the importance of aviation to the economy of the country.

DIVISIONAL COUNCIL 1951

The Divisional Council for 1951 was elected by postal ballot from all members known to be resident in New Zealand.

PRESIDENT
Air Vice-Marshal Sir Arthur Nevill, K.B.E., C.B., B.Sc., A.F.R.Ae.S.

VICE-PRESIDENT
G. N. Roberts, A.R.Ae.S.

HONORARY SECRETARY
T. T. N. Coleridge, B.E., M.I.Mech.E., A.F.R.Ae.S.

ASSISTANT SECRETARY
Squadron Leader J. D. Robins, D.F.C., A.R.Ae.S.

COUNCIL MEMBERS
H. F. T. Adams, M.A., A.M.I.Mech.E., A.F.R.Ae.S.
A. H. T. Brazier, A.F.R.Ae.S.
F. F. J. Butler
Group Captain G. Carter, O.B.E., A.F.R.Ae.S.
A. W. Dingle, A.F.R.Ae.S.
E. A. Gibson, O.B.E., A.M.I.C.E., A.F.R.Ae.S.
I. A. Scott, O.B.E., A.M.I.E.E., A.F.R.Ae.S.

HONORARY TREASURER
A. O. Kemp

Details of the activities of each Branch are as follows:—

AUCKLAND BRANCH

Chairman: G. Bolt, A.F.R.Ae.S.

Council Representative: G. N. Roberts, A.R.Ae.S.

Honorary Secretary: A. Jardine, A.F.R.Ae.S.

Honorary Treasurer: G. Clancey.

Executive Committee: D. J. Patterson, F. A. Reeves, A. E. Vause, A.R.Ae.S., B. G. de Bray, A.F.R.Ae.S., F. Sorrell.

A combined dinner and annual meeting, and eight general meetings were held during the year, the average attendance being 44. The Branch membership is 140. The Branch started with 111 members and during the year 25 members left, mostly because of leaving the district. The losses were more than offset by 54 new members joining during the year.

PALMERSTON NORTH BRANCH

Chairman: C. W. Labette, A.F.R.Ae.S.

Vice-Chairman: A. W. Dingle, A.F.R.Ae.S.

Honorary Secretary: M. R. Roper, A.F.R.Ae.S.

Honorary Treasurer: Miss S. Murphy.

Librarian: Mr. J. S. Brown.

Executive Committee: H. Rolfe, A. J. Smaill, A.R.Ae.S., Sergeant R. Milne (part time), Squadron Leader G. C. Evatt, A.R.Ae.S. (part time).

During the year nine meetings were held and two visits took place, including a film evening held in conjunction with the Annual General Meeting. The average attendance at these meetings was 35. The Branch membership has increased from 63 to 91.

During the year some progress has been made towards setting up an aeronautical library for the Branch. This is being done by arrangement with the Palmerston North Public Library which has set aside a portion of space for this purpose under mutually satisfactory arrangements.

CANTERBURY BRANCH

Chairman: A. H. T. Brazier, A.F.R.Ae.S.

Honorary Secretary: F. Roper.

Honorary Treasurer: F. Brooks, A.R.Ae.S.

Executive Committee: H. F. T. Adams, M.A., A.M.I.Mech.E., A.F.R.Ae.S., A. Palmer, A. N. Mason, T. Moseley.

Activities in this Branch have been handicapped by the fact that a great deal of overtime worked by the majority of members has handicapped evening meetings. Three meetings were held during the year and the total membership of the Branch is 25.

WELLINGTON BRANCH

Chairman: B. Cornthwaite, A.R.Ae.S.

Honorary Secretary: Flight Lieutenant R. B. Bolt, A.R.Ae.S.

Honorary Treasurer: M. L. Clarke.

Executive Committee: J. Gamble, F. J. Steele, A.R.Ae.S., F. F. J. Butler, A.F.R.Ae.S., C. G. Andrews, A.F.R.Ae.S., J. Kerr.

Five evening meetings were held at which the average attendance was 30. During the year the Branch membership increased from 122 to 129.

MEMBERSHIP OF THE DIVISION

During the year the membership of the New Zealand Division has increased slightly. The number of members on the New Zealand register has been as follows:

As at 1st January 1951		*As at 1st January 1952*	
Fellows	1	Fellows	—
Associate Fellows ...	30	Associate Fellows ...	29
Associates	51	Associates	54
Graduates ...	5	Graduates	5
Students	—	Students	1
Companions	1	Companions	3
	88		92

FINANCIAL STATEMENT

A statement showing the financial position of the Division is attached separately. This is as at 31/12/51.

LECTURES

The list of papers and lectures given throughout the Branches during the year is as follows. Some of these have been given at more than one Branch:

(Overseas paper) Operation of Turbo-propeller Aircraft, by C. W. Labette, *Associate Fellow*.

Pathfinding Methods and Experiences, World War II, by Captain George Harvey, Senior Route Pilot, N.A.C.

Some Aspects of Engine Handling, by Mr. Brister, Technical Engine Representative of Bristol Aeroplane Co.

Aviation Fuel Specifications, by E. S. Borthwick, of Shell Company of New Zealand Ltd., Wellington.

Aerial Mapping, by P. van Asch, Managing Director, Aerial Mapping Ltd., Hastings.

Radio Aids, etc., by R. J. Dippy, Divisional Controller of Airways, C.A.B., Air Department, Wellington.

Atomic Energy, by Sir Arthur Nevill, K.B.E., C.B., B.Sc., *Associate Fellow*.

Propeller Gyroscopic Effects Related to Aircraft Accident, by G. B. Bolt.

Pilotage and Navigational Technique Adopted for the Tasman Air Service, by Captain D. Keesing, T.E.A.L.

Precision Methods in Measurement and Machining, by J. B. Brooke.

Some Factors Affecting Air Crew Efficiency, by Wing Commander A. H. Marsh.

Some Uneconomic Aspects of Air Transport, by F. M. Clarke.

Jet Engines with Particular Reference to the D.H. Goblin Engine, by Mr. Burniston.

Some Recent Civil Aircraft Developments in Great Britain, by G. B. Bolt.

Control and Operation of Hercules Engines, by L. G. Brister.

Rocket Flight, by Squadron Leader R. Leonard.

Iron and Steel Production, by Mr. Roper.

Climb Characteristics of Modern Jet Fighter Aircraft, by W. J. Rainbird.

Aviation Greases and Special Products, by P. Ellison, Shell Company of New Zealand Ltd.

Insects, Aircraft and Diseases, by Flight Lieutenant Marshall Liard.

Some Legal and Economic Aspects of International Air Services, by P. P. Heller.

A Recent Survey of Flying Boat Alighting Areas in the Pacific, by C. C. Brodie.

The de Havilland Goblin Engine, by Mr. Burniston.

A number of films were shown at meetings and there were also a number of general discussions.

A number of Branch visits were made, notably to the Laboratories of the Shell Company of New Zealand Ltd., the Department of Scientific and Industrial Research and the R.N.Z.A.F. Station, Ohakea.

DIVISIONAL COUNCIL 1952

At the Annual General Meeting of the Division, held at Wellington on 11th March 1952, the Report and Financial Statement were adopted and the election of the following members of Council was announced (the officers for the year were to be elected at the next meeting):—

H. F. T. Adams, A.F.R.Ae.S. (Canterbury Branch), B. G. de Bray (Auckland), G. N. Roberts, A.R.Ae.S. (Auckland Branch), A. W. Dingle, A.F.R.Ae.S. (Palmerston North Branch), C. W. Labette, A.F.R.Ae.S. (Palmerston North Branch), Sir Arthur Nevill, K.B.E., C.B., A.F.R.Ae.S., Group Captain G. Carter, O.B.E., A.F.R.Ae.S., Squadron Leader J. D. Robins, D.F.C., A.R.Ae.S., T. T. N. Coleridge, A.F.R.Ae.S., E. A. Gibson, O.B.E., A.F.R.Ae.S., C. G. Andrews, A.F.R.Ae.S., F. F. J. Butler, A.F.R.Ae.S.

ROYAL AERONAUTICAL SOCIETY—NEW ZEALAND DIVISION
STATEMENT OF RECEIPTS AND PAYMENTS FOR PERIOD 1st JANUARY 1951 TO 31st DECEMBER 1951

Receipts	£	s.	d.	*Payments*	£	s.	d.
Balance at 1/1/51				Transfer of subscriptions to Royal Aeronautical Society, London ...	78	5	0
(*a*) National Bank of New Zealand ...	313	16	2	Reimbursement of subscriptions to 31/12/50:			
(*b*) Petty Cash ...	1	0	6	Auckland Branch ...	4	5	0
Subscriptions, entrance fees and sale of badges ...	135	1	0	Palmerston North Branch	1	15	0
				Wellington Branch ...	7	0	0
				Canterbury Branch ...	1	15	0
				Advance on account of subscriptions for year ended 31/12/51:			
				Auckland Branch ...	6	0	0
				Palmerston North Branch	3	0	0
				Wellington Branch ...	6	0	0
				Canterbury Branch ...	2	0	0
				Grants:			
				Palmerston North Branch	10	0	0
				Canterbury Branch ...	10	0	0
				Visible Card Index system	5	18	0
				Postage Stamps	5	13	6
				Stationery		5	9
				Whites Air Directory ...		15	0
				Bank Charges and Cheque Book		14	0
				Exchange on Cheques ...		3	0
				Balances as at 31/12/51			
				(*a*) National Bank of New Zealand Ltd. ...	302	0	8
				(*b*) Petty Cash	4	7	9
	£449	17	8		£449	17	8

I have audited the Accounts of the Royal Aeronautical Society (N.Z. Division) and the above is a true and correct statement of receipts and payments recorded.

(*Signed*) B. W. J. HOULT
B. Com. A.R.A.N.Z.
Honorary Auditor

11th March 1952

REVIEWS

The following are reviewed:—

Theory of Perfectly Plastic Solids
Military Aircraft of the U.S.S.R.
Aircraft Materials and Processes
English-French Vocabulary of Aeronautical Terms
Aircraft Gyroscopic Flight Instruments
Flight Eastward—*Fiction*
The Happy Valley—*Fiction*

THEORY OF PERFECTLY PLASTIC SOLIDS. W. Prager and P. G. Hodge, Jun. John Wiley & Sons, New York. Chapman & Hall, London, 1951. 264 pages, index. $5.50, 44s. net.

All students of 'Strength of Materials' know that its greater part—concerned with consequences of Hooke's Law—has close relation with the *elastic* behaviour of materials but little bearing on the question of their *strength*. And they know the reason—that failure of real materials is preceded by a 'ductile' stage in which the strain, so far from being a linear, is not even a single-valued function of the stress. They readily accept that to understand it they must have recourse not to theory but to experiment.

This state of affairs will not satisfy the curious, and attempts to devise a theory of *plastic* straining were begun long ago, notably by Saint-Venant. In the past 30 years they have become more numerous, and by now 'Plasticity'—the theory of ideal materials in which infinite strain can consist with finite stress—has a very considerable literature. Partly by reason of its difficulty it will take long, I suspect, to exercise much influence on practice; but for men who have the mathematical equipment it provides a limitless field of intriguing problems. All that they need is to be brought up to the 'front line' of the attack.

Here, in the space of 257 octavo pages (very well produced) Professors Prager and Hodge have given them all that could be expected of "an introductory treatment . . . . written at an intermediate level". All and more; for not only is the book fully documented, but problems are appended to every chapter whereby a reader can test his grasp of its contents. The length allowed for this review will not permit any detailed criticism of the mathematical presentation: I can only state impressions which may assist a reader to decide whether purchase of the book is worth his while. I would say, and emphatically, that it is *if* he looks for more than "something helpful in design"; and in particular I am pleased by its frequent reminders that all assumptions (about real materials) are *tentative*. Too often, in this field of study, assumptions dictated mainly by the need to simplify are later credited with the solidity of physical law; and for no apparent reason except the vastness of the theoretical superstructure that has been based upon them. I myself regard that superstructure as necessary *because only thereby can the assumptions be brought to the test of experiment.* For no one yet has *directly* measured stress or strain; we can only relate (experimentally) *resultant* actions with *integrated* strains—*i.e.* with *displacements.*

My one regret—not solely due, I hope, to insular thinking—is that a fairly lengthy Author Index contains no reference to Professor J. F. Baker's research group in Cambridge (England) except one citation of B. G. Neal (and this not concerned with his Royal Society paper). That group's investigation of the plastic behaviour of framed structures (started some 16 years ago, if memory serves) admittedly is not at all points severely logical—but neither is the accepted 'engineers' theory' of *elastic* flexure, about which A. E. H. Love said some hard things in his time! It might be deemed inappropriate to a strictly mathematical treatise; but this purports to be a text book for (among others) *engineering* students, and its second chapter has the title "Trusses and Beams". I have already urged the necessity of *experiments* in this field; and whatever be the *logical* shortcomings of its treatment, our Cambridge school has thoroughly tested its every step.—R.V.S.

MILITARY AIRCRAFT OF THE U.S.S.R. Charles W. Cain and Denys J. Voaden. Herbert Jenkins, London, 1952. 74 pp. Illustrated. 3s. 6d. net.

There can be few subjects of greater interest today than Russian Military Aircraft and this small, compact booklet illustrated with photographs, drawings, three-view silhouettes, and including a short account of all that is known of each aircraft type, will attract a wide circle of readers, particularly those interested in aircraft recognition.

The main attraction of the booklet is its silhouette drawings. Whether they are technically more accurate than any previously published no one this side of the Iron Curtain can perhaps say. Based on information sifted from all that has been previously published about Soviet aircraft, they are probably as accurate as anything could be, and judging them on that basis, they *look* right, which, after all, is as much as is needed by most people who want to recognise Soviet aircraft. The pages devoted to "Lesser Known Types" should be treated with suspicion.

The aircraft caricatures are neat and, in the main, capture the characteristic impressions of the aeroplanes they represent. We would quarrel with some however, particularly that of the IL-12, which looks more characteristic of the Viking. It is a pity that the type-face used throughout is so small and trying. But these are small points and altogether the book is well worth the 3s. 6d. asked.

AIRCRAFT MATERIALS AND PROCESSES. George F. Titterton. Pitman Publishing Corporation, New York, 1951. 359 pp., 65 figures. 35s.

This is a remarkable American book. It qualifies for this description on the basis of not less than two counts. It is remarkable in having attained four editions and, from the British point of view, it is also remarkable in being poor to a degree—in fact, to use an American phrase in a somewhat unusual sense—it constitutes a new high in low.

The author starts with a series of definitions. Although long ago the U.S. Bureau of Standards in Circular C.447 produced a most admirable set of definitions relating to the mechanical properties of metals and alloys, Mr. Titterton scorns, or is perhaps ignorant of these. He must produce his own, at least one of which is inaccurate, and most are so lacking in conciseness as to merit being classed as woolly.

Although it is a matter of common knowledge that the majority of airframes being built in Great Britain and in the United States are about 70 per cent. aluminium alloy, the author devotes exclusively to these only two of his twenty-two chapters. On the other hand, to wood, glue, fabric, dope, plastics, transparent materials and to rubber and synthetic rubber he gives five, admittedly shorter, ones.

From his ability to discuss the consequences of work-hardening without reference to the Bauschinger effect, and to dispose of fatigue without drawing attention to the absence, in the case of the age-hardening alloys, of any relationship between Ultimate Tensile Stress and Endurance Limit, one would conclude that Mr. Titterton is no physical metallurgist, while his failure to refer to the causes and effects of crazing of acrylic transparencies indicates a quite remarkable capacity to look at a very grave defect with an extremely blind eye.

ENGLISH-FRENCH VOCABULARY OF AERONAUTICAL TERMS. Prepared by M. Chalmette. An *Aircraft Engineering* Monograph. London 1952. 36 pp. 4s.

At first glance it seemed that this *Aircraft Engineering* Monograph was going to fill a long felt want. There are quite a number of French aeronautical journals containing excellent technical articles but the rapid growth of the science leaves a "reading knowledge of French" lagging a little. A translation of B.S.185 would go a long way towards rectifying this. The Vocabulary does just this for parts 1 and 2 but unfortunately it is entirely English/French—an excellent arrangement for a Frenchman or an Englishman writing a Blériot Lecture but of very little use to the reader wrestling with *Technique et Science Aéronautiques* or *La Recherche Aéronautique*.

AIRCRAFT GYROSCOPIC FLIGHT INSTRUMENTS. Sperry Gyroscope Co. Ltd., Great West Road, Brentford, Middlesex, 1952. 84 pp. Illustrated. 3s. 6d. net. *Fifth Edition.*

A new edition of this booklet has just been published, the fifth since the first edition of 1946. It contains a new chapter on the Zero Reader flight director and also introduces a comprehensive explanation of turn errors experienced with the Gyro Horizon; it has, in fact, been extensively rearranged to bring it completely up-to-date. A total of 6,500 copies of the first four editions has been issued, and the booklet has proved very popular with all sections of the Industry.

CALIBRATION OF COMMERCIAL RADIO FIELD-STRENGTH METERS AT THE NATIONAL BUREAU OF STANDARDS. Frank M. Greene. National Bureau of Standards Circular 517, iii, 5 pp. Government Printing Office, Washington 25, D.C., 1952. 10 cents.

Among the services offered by the National Bureau of Standards is the calibration of certain types of radio field-strength meters in the frequency range 10 kc. to 300 mc. This Circular describes briefly the standards and methods used in such calibration.

FLIGHT EASTWARD. John Fores. Jonathan Cape. London 1952. 255 pp. 12s. 6d. net. *Fiction.*

The author has undertaken a difficult task in concocting a novel from the emotions and reactions of the crew and passengers in an air liner bound from England to Calcutta. He gives himself more time by including an emergency landing during which one of the crew and the attractive girl passenger find they have a lot in common. The same emergency introduces the crime element which, later, provides the death element in the form of suicide.

Mr. Fores is a former navigator and this accounts for the excellence of the "authentic atmosphere" although this takes up too much of the novel's length.

THE HAPPY VALLEY. Jules Roy. Gollancz. London, 1952. 224 pp. 12s. 6d. net.

The Happy Valley is the Ruhr and the book revolves round the French bomber crew of B for Beer which performs most of its thirty odd operations over that unhealthy territory. The whole of the crew except for the pilot give one the impression that they would not have passed any psychiatrist's examination before their first flight, let alone complete a longer than usual tour unscathed. The captain of the bomber is Chevrier, the bomb-aimer, and he spends most of his time in the Halifax wondering how they contrive to avoid colliding with fellow-raiders (especially on the 1,200 raid) and worrying about his crew's reactions.

The book does, however, have the virtue that it makes us realise that not all the men who flew the bombers and fighters were young men without a care in the world, free from any form of nerves and addicted to the three Straussian remedies of Wine, Women and Song.

ADDITIONS TO THE LIBRARY

The following have been added to the Library. Books and papers marked with an asterisk may not be taken out on loan. The titles of pamphlets are printed in italics.

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64—*The measurement of heat transfer and skin friction at supersonic speeds. Part II. Boundary layer measurements on a flat plate at $M=2.5$ and zero heat transfer. R. J. Monaghan and J. E. Johnson.*
65—*Flight tests on the Youngman-Baynes high-lift experimental aircraft. D. Lean.*
66—*Designing to avoid dangerous behaviour of an aircraft due to the effects on control hinge moments of ice on the leading edge of the fixed surface. D. E. Morris.*

67—*Draft corrections for water surface deflection under No. 1 carriage of the R.A.E. seaplane tank. T. B. Owen.*
68—*Approximate two-dimensional aerofoil theory. Part I. Velocity distributions for symmetrical aerofoils. S. Goldstein.*
69—*Approximate two-dimensional aerofoil theory. Part II. Velocity distributions for cambered aerofoils. S. Goldstein.*
70—*Approximate two-dimensional aerofoil theory. Part III. Approximate designs of symmetrical aerofoils for specified pressure distributions. S. Goldstein.*
71—*Approximate two-dimensional aerofoil theory. Part IV. The design of centre lines. S. Goldstein.*
72—*Approximate two-dimensional aerofoil theory. Part V. The positions of maximum velocity and theoretical C_L ranges. S. Goldstein.*
73—*Approximate two-dimensional aerofoil theory. Part VI. Aerofoils with hinged flaps. S. Goldstein and J. H. Preston.*

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2431—*General handling tests of the Sikorsky R-4B helicopter (Hoverfly Mk. I). W. Stewart.*
2446—*Flight tests on the performance of Meteor IV (a twin-engined, single-seat, jet fighter). F. Smith, D. J. Higton and R. H. Plascott.*
2580—*Suction-slot ducting design. A. G. Rawcliffe.*
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2596—*An impulse-momentum method for calculating landing-gear contact conditions in eccentric landings. R. T. Yntema and B. Milwitzky.*

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